MFA

YEARBOOK

50

2006

RESEARCH INSTITUTE FOR TECHNICAL PHYSICS AND MATERIALS SCIENCE

HUNGARIAN ACADEMY OF SCIENCES

http://www.mfa.kfki.hu

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Hungarian Academy of Sciences

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MTA MFA Yearbook 2006

Editors: Zoltán Hajnal, Zsolt Zolnai
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Contents

Director’s foreword

“Consequent efforts are bearing fruits” – that is, how we could summarise the consequences of the last year in the life of the Research Institute for Technical Physics and Materials Science- MFA.

The institute was operating in 2006 still in the well established organisation structure with four research divisions, representing the four major research directions at MFA. In the control of only two research groups there were changes due to retirement: the Laboratory of Nanoceramics and nanocomposites is now headed by *Csaba Balázsi* and the Laboratory for Thin film nanosystems by *György Molnár*. As a matter of fact, meanwhile all of the research activities were centred around the exploration of selected areas of nanoscience and exploitation of a nanotechnology results in different integrated system applications. This led to a further concentration of the albeit still rather broad spectrum of research with the general emphasis on *utilisation of nanodimensions*. The support of the successfully audited quality assurance system: ISO 9001:2000 especially in the utilisation of the fundamental research results in various applications, EU projects, R&D contracts proved to be indispensable. Following the efforts for attracting younger co-workers, in 2006 again nine new colleagues joined the institute’s staff. *Ferenc Beleznay* became “professor emeritus instituti”, three new PhDs, one Dr.habil. title and a new professor assignment were obtained by our colleagues.

One can state again with satisfaction that, in the last year of the assignment of the current director the co-operation among different groups further improved, thereby strengthening the institute’s integrity and impact. The decision-making was effectively supported by the advisory councils of the director. The main responsibility for the scientific strategy of the divisions lies with the heads of the divisions, constituting the Director’s Council. Also the Board of Institute, headed by the past-director and consisting of external experts from various universities, provided valuable orientation and guidance. The 8 member strong Scientific Council did an excellent job in raising the level of PhD education by closely following the progress of all the 21 young scientists working toward the PhD at MFA. Maintaining the high quality of the regular scientific seminars, close attention to the high standard of publications, as well as the yearly accounting of the individual researchers and research groups about their scientific activities, were all well mastered by the Council. This year again the international contacts were extended, which are systematically explored also for the post-doc training of young MFA researchers.

The increase of the level of public awareness concerning the results and achievements of our institute and the research field as a whole in a period of increasing financing difficulties in research in Hungary was one of the foremost tasks in 2006. Besides attending the major scientific conferences worldwide, and lecturing at numerous seminars and meetings for dedicated and wider audience in Hungary, our colleagues appeared over a dozen time on the screen and at the microphones of the Hungarian audio-video media. *The Yearbook 2006 in your hands is also one general way of publicising the recent achievements.*

Statistical and substantial details of the scientific output of MFA you will find in this booklet. We are especially proud this year of the publication of the Hungarian book of our senior scientist, *Zoltán Juhász* entitled: "The ancient language of music" (A zene ősnyelve – in Hungarian, at Fríg Publishing House, Budapest). This is an éclat example of how the results of classification by adaptive filtering originally elaborated for the treatment of materials research problems can be adopted to elucidate trends in the evolution of mathematically described tunes in folk-music. We are equally proud of the special international attention (E-MRS conference) accompanying the pioneering work of the group headed by our scientific advisor, *László P. Biró*, studying photonic crystals in flora and fauna, in order to learn and utilise their exceptional properties in artificial systems. Both of the above examples reflect the growing importance of "inter- or multidisciplinarity" characterising the field of materials research especially in the nanodimensions. *This openness for new challenges, for cross-fertilisation and readiness to collaboration with virtually distant disciplines even, is one of greatest strengths of our institute.*

Despite of lack of dedicated support for the extension of research infrastructure within the research network of HAS also in 2006 we were able to allocate a substantial amount from other incomes for this purpose. Among others the construction of a new chemical lab for microsystems technology, the purchase of a new solar-panel test station and acquisition of processing equipment like a HeNe laser for PLD, a Langmuir-Blodgett film-coater, and an extension of the central computer network capabilities could be facilitated.

The first, fully owned spin-off company of MFA, the *ANTE Innovation Technologies Ltd.* started to establish the necessary industrial contacts for the efficient marketing of MFA services and prepared for the start of some pilot production activities. A new smart sensor process-development result and the associated patent application enabled MFA to join forces with the *Catholic University Péter Pázmány* and the pharma-company *Gedeon Richter Inc.* to set up a joint venture for the utilisation of the developed integrated bulk-micromachined tactile-sensor arrays with on-chip CMOS logic in system applications.

The submission of successful research proposals was never more desirable than in 2006. In the revenues of MFA the ratio of subsidies provided by the parliament via the Hungarian Academy of Sciences decreased further. This year the R&D project financing surmounted for the first time the amount of subsidies. In 2006 MFA became a member of successful consortia in two projects of the last FP6 calls. Preferably, the ratio of support coming from EU funds in the income should also be increased. From September 2006. a dedicated project manager is supporting the director in coordination of the FP7 proposals. Also a lot of effort had to be invested in the formation of industrial and research alliances in order to mobilise EU resources from the structural and cohesion funds for the improvement of the domestic infrastructure for nanotech research in the coming few years. This also required the instalment of a new innovation manager position aiding the director.

Mastering the difficulties in 2006, caused by an extreme increase in burocracy and liquidity problems due to irregular payments, would not have been possible without the enthusiastic and devoted efforts of the financial administration. Despite all of these problems and shortcomings, the record results of the previous year could be improved by 9%! *2006 was the best financial year so far since the existence of the Research Institute for Technical Physics and Materials Science with the revenues of HUF 1.6 billion (€ 6.4M).*

In view of the introduced and foreseeable austerity measures, however, realistically we can not expect the experienced growth to continue in the years to come. Still we hope to possess the solid base in research qualities, international co-operation, the skills and adaptation capability, which will allow us to maintain the achieved high scientific level also in the year of the 50th anniversary of the institute (of its predecessor, the Research Institute for Technical Physics- MFKI) being the 10th anniversary of MFA, too.

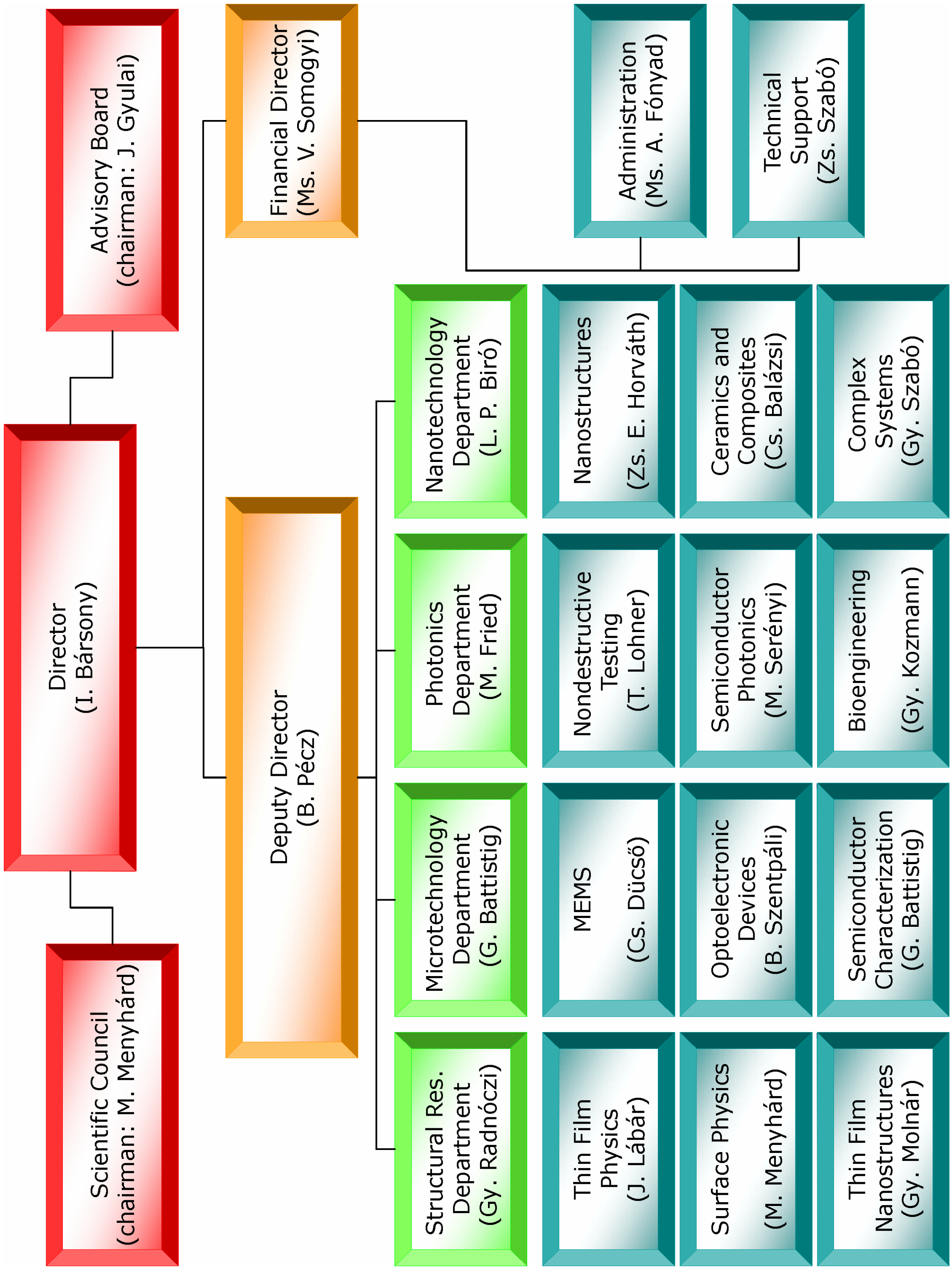
Budapest, March 31, 2007.

István Bársony

General Information

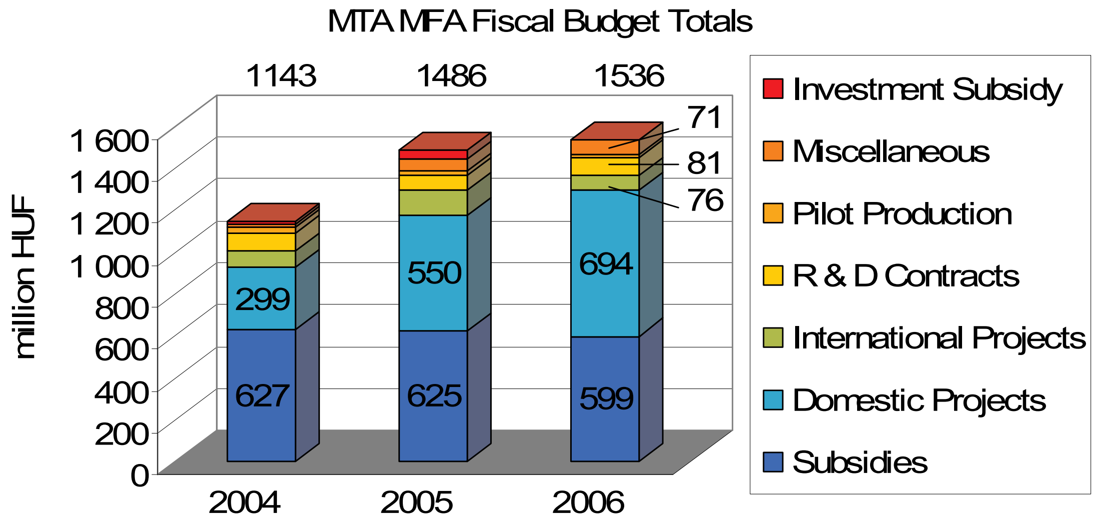
Organisation

The Institute is organized in four Departments representing the research fields of our activities. Each Department is divided into three Laboratories, some of which are centered around given technological infrastructure, others are more readily described by their focus of interest.
Life of the whole organization is supported by a strong administrative and technical support branch. Top level decision making in scientific and policy issues is assisted by the two boards.

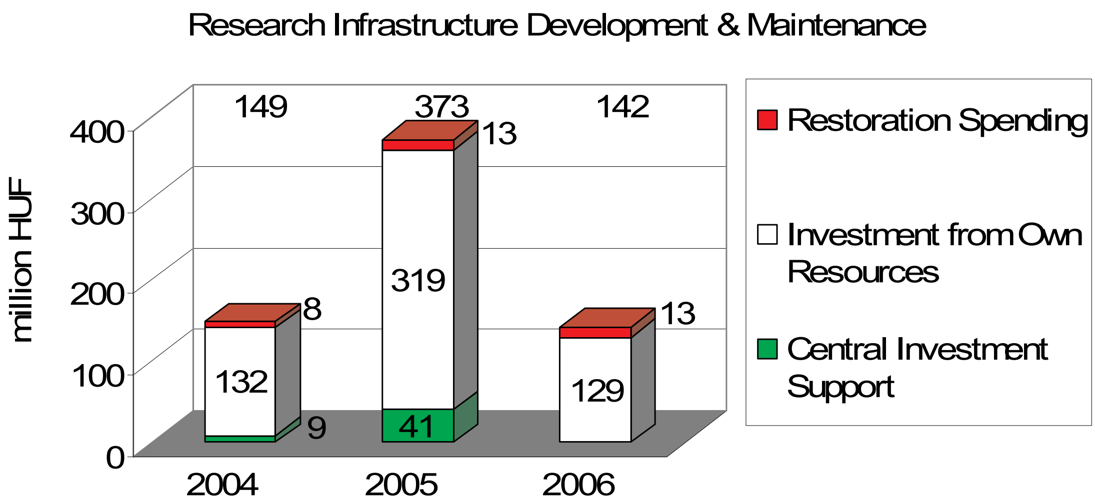


Key Financial Figures

The total budget of MFA has grown substantially over the last couple of years, and reached € 6.1 million in 2006.[1]
As the figures below show, successful applications for domestic and international research funding could not only balance the decreasing subsidies, but provided a basis for substantial growth in the last two years.



In spite of diminishing state participation, the Institute continuously maintains and develops its research infrastructure.



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[1] Figures of this section are in millions of Hungarian Forints.
1 million HUF ≈ 4000 €

Prizes and Honours

Order of Merit of the Hungarian Republic – Officer's Cross
Prof. Ferenc BELEZNAY

Order of Merit of the Hungarian Republic – Knight Cross
Dr. György KOZMANN

EPS Fellow – honours from the European Physical Society
Prof. József GYULAI
"For your enthusiastic and very influental services in establishing closer contacts between the physicists and your outreach activities who helped keeping high the interest of the Hungarian public in physical research."

Zoltán Gyulai Prize of the Roland Eötvös Physical Society
László Péter BIRÓ, D.SC.

Pro Custodia prize
Edvárd BADALJÁN

Academia Europaea, Burgen Scholar 2006
Antal Adolf KOÓS

Professor Emeritus Instituti
Prof. Ferenc BELEZNAY

MFA Prize
Miklós MENYHÁRD, D.SC.
For the outstanding scientific results contributing to the development of surface physics during his research activity for decades, and for his constructive, critical, and efficient work presented in the management of the MFA Scientific Council.

MFA Prize
Mária ÁDÁM
For her exemplary achievements practiced for decades in the microtechnological projects of MFA and for her leadership in the development of integrated tactile sensors.

MFA Junior Prize
Norbert NAGY
In recognition of his outstanding results on the preparation of self-assembled photonic structures and for his enthusiastic initiatives on behalf of the MFA.

János Bolyai Postdoctoral Grant
Csaba BALAZSI

József Öveges Research Grant

Csaba BALAZSI, György MOLNAR, Zsolt ZOLNAI

Dr. György Ferenczi Memorial Prize

Zoltán OSVATH, György Zoltán RADNOCZI

„Best Ph.D. Thesis 2006" Price winner of czecho-slovakian Microscopic Society

Katarína SEDLÁCKOVÁ

„Best publication on microscopy" Price winner of Hungarian Microscopic Society

Katarína SEDLÁCKOVÁ and Bernadett VEISZ

(K. Sedláčková, P. Lobotka, I. Vávra, G. Radnóczi: Structural, electrical and magnetic properties of carbon-nickel composite thin films, *Carbon* **43** 2192 (2005))

Best Poster of the Day Award

Norbert NAGY

(N. NAGY, A. E. PAP, A. DEÁK, J. VOLK, E. HORVÁTH, Z. HÓRVÖLGYI, I BÁRSONY: "Regular patterning of PS substrates by a self-assembled mask", The 5th Int. Conf. Porous Semiconductors – Science and Technology, (PSST 2006), Sitges-Barcelona)

Best Poster Award in the "Trends in Nanotechnology (TNT 2006)" conference, Grenoble, France

Zoltán OSVÁTH

(Z. OSVÁTH, L. TAPASZTÓ, G. VÉRTESY, Z. E. HORVÁTH, A. A. KOÓS, J. GYULAI, L. P. BIRÓ: "STM imgaing of carbon nanotube defects")

Scientific Students' Conference (TDK) 2nd prize

Péter KOZMA, undergraduate

(Roland Eötvös University)

"Noncontact thickness measurement using optical method"

(Advisor at MFA: András HÁMORI)

Scientific Students' Conference (TDK) 2nd prize

Márton BEIN, undergraduate

(Budapest University of Technology and Economics)

"STM caracterization of functionalized nanotubes"

(Advisor at MFA: Antal Adolf KOÓS)

Nanoscience Highlight

Electron scattering on defect sites of carbon nanotubes

Levente TAPASZTÓ

MFA Nanostructures Laboratory

In order to permit the continuous downscaling of the electronic devices, alternative technologies are needed. Molecular electronics is a potential new technology that may fulfill this need. One of the most promising building blocks of the molecular electronic devices is the family of carbon nanostructures. Metallic carbon nanotubes can be used as molecular leads, while the semiconducting ones can be operated as diodes or field effect transistors.

As the size of these devices becomes comparable to the coherence length of the electrons, the arising quantum mechanical effects become of major importance in their operation. While in classical devices the presence of defects only contributed to the resistance of the device, in carbon nanotubes the scattering of the electrons on the defect sites gives rise to complex long-range interference effects, which are of crucial importance regarding the electronic behavior of the device. Hence the detailed understanding of these effects is essential in the development of novel molecular electronic devices based on carbon nanotubes.

There are only a few experimental methods which enable us to directly study the effects of electron scattering on the defect sites of carbon nanotubes. Scanning Tunneling Microscopy (STM) is a promising method, since it is able to provide information both on atomic and electronic structure of the nanotubes.

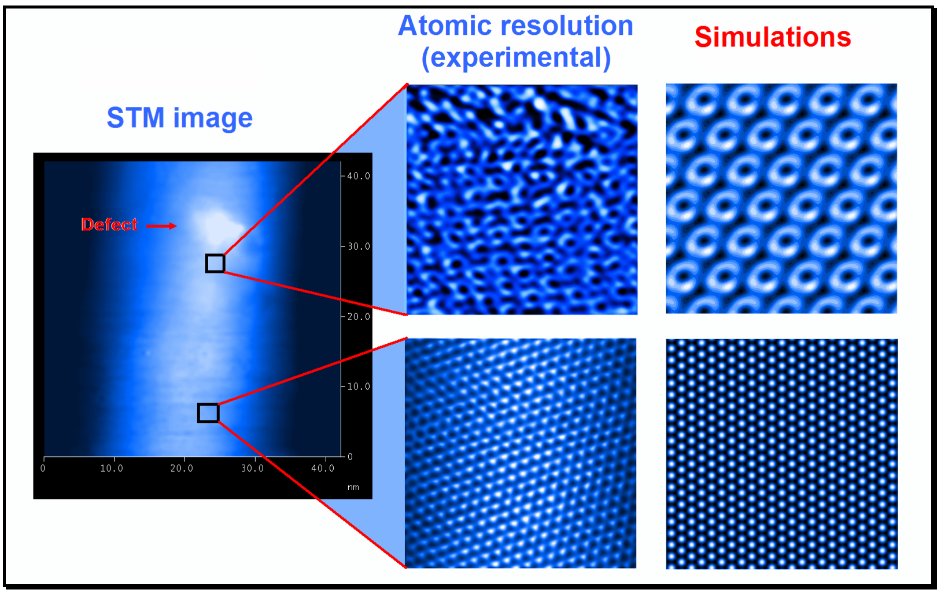


Fig. 1

Fig. 1. above shows an STM image of a multi-walled carbon nanotube subjected to an acidic treatment in order to attach functional groups to its sidewall. The hillock-like protrusion observed on the wall of the tube is the signature of such a group. The atomic structure of the defect (functional group) cannot be observed on the STM image due to the strong local perturbation of the electronic structure, namely the presence of localized states at the defect site. However the detailed study of these localized states may provide us with information on the structure of the defect.

The observation of long-range effects caused by the presence of the defect became possible when atomic resolution was achieved in the vicinity of the defect site. According to expectations, the triangular atomic lattice of the graphite was observed on the defect free region of the nanotube, however in the vicinity of the defect site a specific electron density pattern was revealed, which showed no direct correlation to the underlying atomic structure of the nanotube. In order to be able to interpret the STM images observed near the defect site a detailed theoretical investigation is required.

We have developed a theoretical model, which interprets the modified electron density distribution near the defect site, as a consequence of the interference between the regular and defect scattered wave functions of the nanotube. Taking into account the linear dispersion relation near the Fermi level of the nanotubes and the restricted number of available scattered states we were able to identify two scattering mechanisms taking place at the defect sites of the nanotubes: the small respectively large momentum scattering processes.

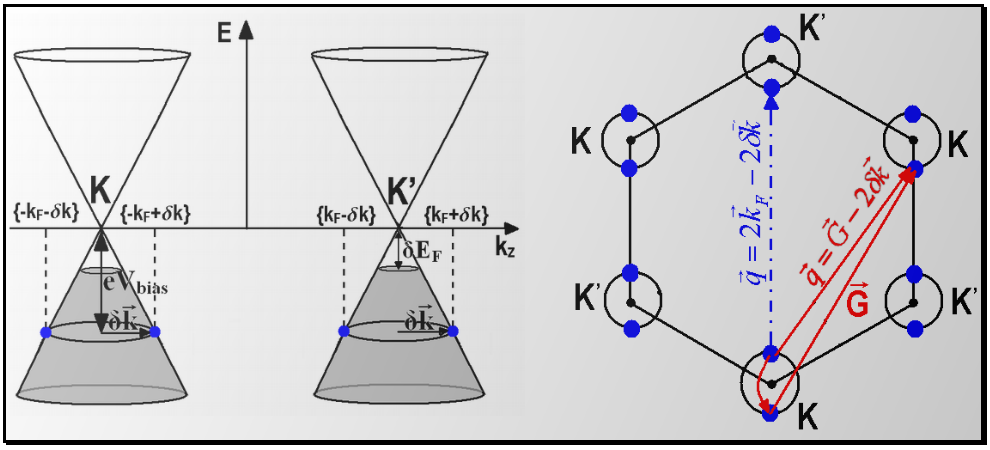


Fig. 2

Considering the above mentioned scattering mechanisms and the available scattered states near the Fermi level of the nanotube, we were able to reproduce the observed electron density distribution near the defect site.

Our theoretical model was also applied successfully in the interpretation of atomic resolution STM images observed on a multi-wall carbon nanotube bend junction. Nanotube bend junctions are formed due to the incorporation of pentagon-heptagon defect pairs in the hexagonal structure of the straight nanotube during the growth process. The scattering

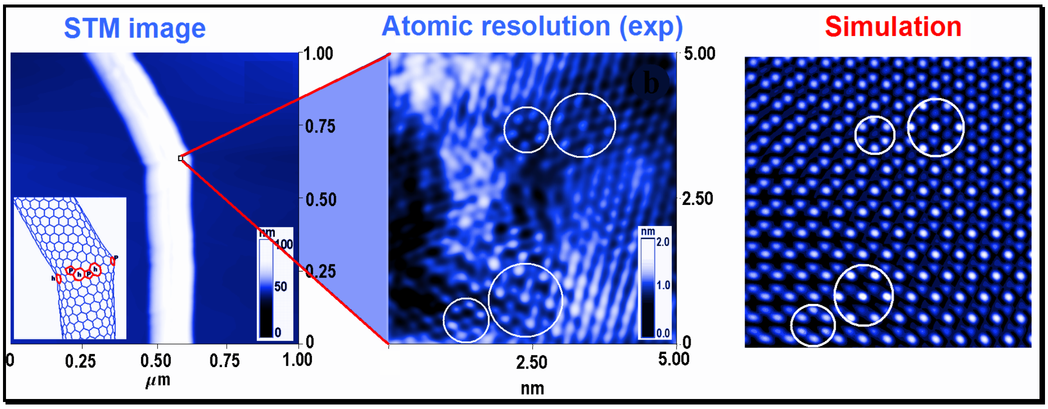


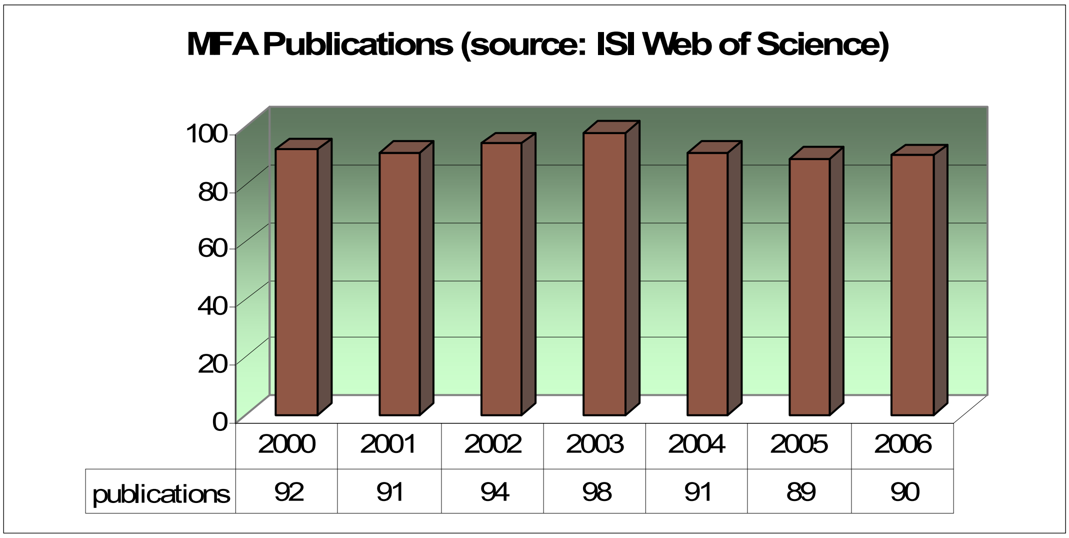
Fig. 3

processes taking place in the junction region could also be described using our theoretical model.

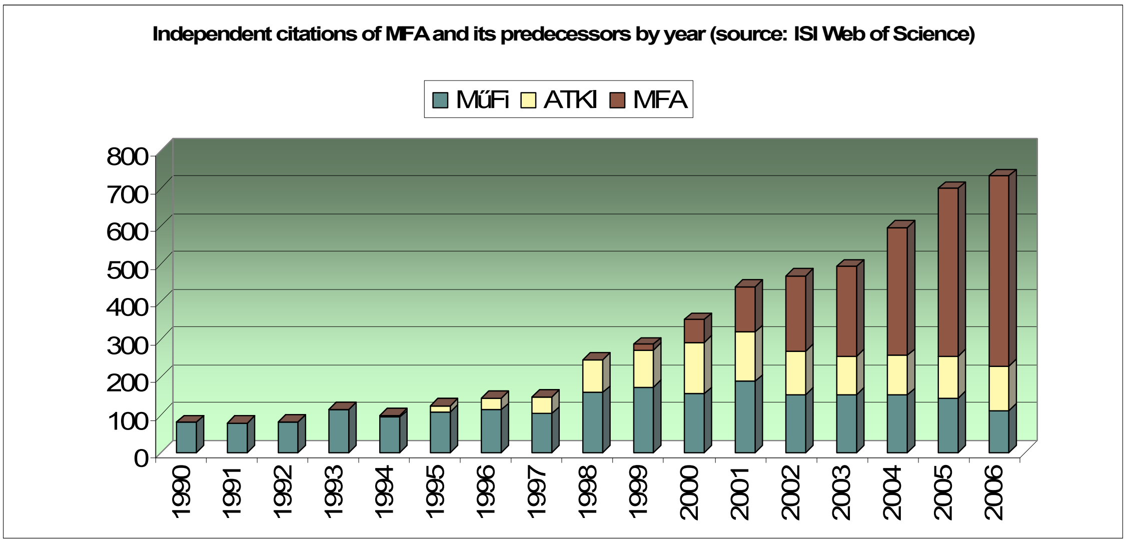
To conclude, we have demonstrated that the electron density modulations near the defect sites of carbon nanotubes observed in STM measurements are due to the interference of the defect scattered electronic wave functions. Hence the electron scattering processes – of particular importance in understanding the operation of molecular electronic devices – can be experimentally investigated by STM measurements.

Scientometry (International Impact)

MFA continuously maintains a publication rate over 1.0/researcher/year, based on the data of the ISI Web of Science.[2] This is also comparable to the output of other institutes of the Hungarian Academy of Sciences. However, the total number of publications (see complete list from page 98), including those not listed in international databases is twice that.



In terms of independent citations, looking at the figure below one can see that MFA and its predecessors' results enjoy a growing interest in the S&T community year by year.



2 http://www.isiknowledge.com

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Institute of Physical Chemistry, Polish Academy of Sciences, Warsaw, Poland

Scientific Reports

Structural Research Department

Surface Physics Laboratory	**Thin Film Physics Laboratory**	**Thin Film Nanostructures Laboratory**
Head: Miklós MENYHÁRD, D.Sc. **Staff:** György GERGELY, Prof. Emeritus, D.Sc. Sándor GURBÁN, M.SC. Attila SULYOK, Ph.D. Péter SÜLE, Ph.D. **PhD Students (Advisor):** László KÓTIS (Miklós MENYHÁRD)	**Head:** János LÁBÁR, D.Sc. **Staff:** Árpád BARNA, Prof. Emeritus, D.Sc. ÁRPÁDNÉ BARNA, technician Péter BARNA B., Prof. Emeritus, D.Sc. Sándor CSEPREGHY, engineer Zsolt CZIGÁNY, Ph.D. László DOBOS, Ph.D. TAMÁSNÉ GESZTI, M.SC. FERENCNÉ GLÁZER, lab. assistant Éva HEGEDŰS, Ph.D. Andrea JAKAB, lab. assistant Viktória KIS, Ph.D. András KOVÁCS, Ph.D. (on leave at Osaka, Japan) ANTALNÉ KOVÁCS, secretary Andor KOVÁCS, engineer István KOVÁCS, engineer Béla PÉCZ, D.Sc., Deputy director László PUSKÁS, technician György RADNÓCZI, D.Sc, Head of department György SÁFRÁN, Ph.D. Katarína SEDLÁCKOVÁ, Ph.D. Lajos TÓTH, Ph.D. Bernadett VEISZ, Ph.D. **PhD Students (Advisor):** Róbert GRASIN (János LÁBÁR) György KOVÁCS (György RADNÓCZI) Fanni MISJÁK (Péter BARNA B., György RADNÓCZI) György Z. RADNÓCZI (Béla PÉCZ) Marianna SZERENCSI (György RADNÓCZI) Lajos SZÉKELY (Péter BARNA B.)	**Head:** György MOLNÁR, Ph.D. **Staff:** Gábor PETŐ, D.Sc. Tamás HORÁNYI, Ph.D. Albert KARACS, M.SC. György LEHEL, technician **PhD Students (Advisor):** Zsófia BAJI (Gábor PETŐ)

Surface Physics Laboratory

Experimental determination of the inelastic mean free path (IMFP) of electrons in SiO_2 applying surface excitation parameter (SEP)

(Supported by the Hungarian-Polish bilateral agreement No. PL-11/2002)

Sándor GURBÁN, György GERGELY, J. TÓTH, D. VARGA, A. JABLONSKI, Miklós MENYHÁRD

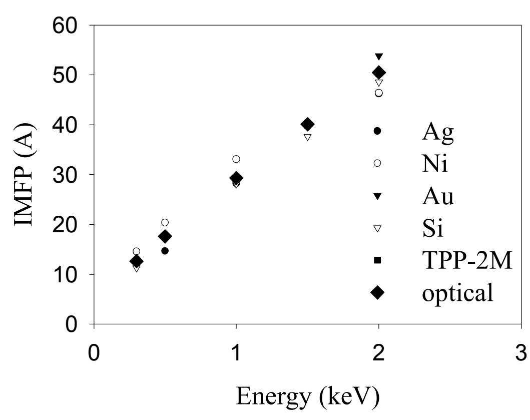


Fig. 1

The elastic peak electron spectroscopy (EPES) is applied to determine the surface excitation parameter (SEP). The SEP is an important parameter with which the calculated IMFP values, for the bulk material, can be corrected and adjusted to the experimental values. In Fig. 1 we show the corrected IMFP values determined by EPES, and the corresponding ones recommended by TPP-2M and optical measurements. The reasonable agreement shows the accuracy of our method.

Derivation of ion mixing efficiency

(NKFP 3A/071/2004)

Miklós MENYHÁRD, Péter SÜLE

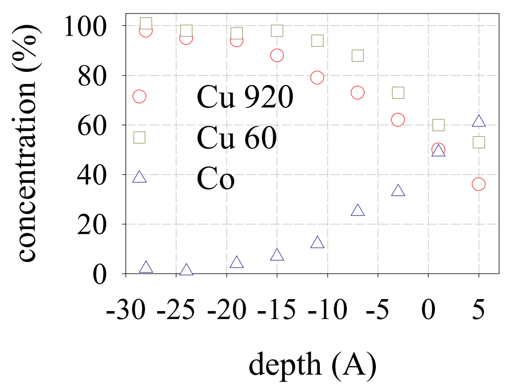


Fig. 2

The extent of ion mixing strongly depends on parameters (energy, type, angle of incidence) of the bombarding projectile. In order to characterize the susceptibility of the given material for ion mixing we should consider the mixing occuring to unit fluence and deposited energy. This parameter is the mixing efficiency, which has not been derived yet from ion mixing experiments performed at low ion energies. We have developed a new algorithm for such calculation. We considered the part of the depth profile determined by Auger Electron Spectroscopy (AES) on a Co/Cu system, as shown in Fig. 2.

The fluence was determined from the measurement, while the deposited energy from SRIM simulation, respectively. The mixing efficiency was found to be 0.08 ±0.01 nm^5/keV. Molecular dynamics simulations, carried out for the same sputtering conditions, provided similar results. The value found for the mixing efficiency proved that ballistic effects responsible for the mixing phenomena.

(For details see: M. Menyhárd, P. Süle: Experimental and theoretical determination of the mixing efficiency of low-energy Ar^+ bombardment: case study of the Cu/Co system, Surface and Interface Analysis **39** 487-492 (2007); P. Süle, M. Menyhárd: Intermixing in Cu/Co: molecular dinamics simulations and Auger electron spectroscopy depth profiling, Defect and Diffusion Forum **264** 19-25 (2007)).

Anomalous asymmetric interdiffusion in Pt/Ti

(Hungarian Scientific Research Fund under Grant No. F 037710, HPC-Europa RII3-CT-2003-506079, and NKFP 3A/071/2004)

Péter SÜLE, Miklós MENYHÁRD, László KÓTIS, W. F. EGELHOFF Jr.

Transient enhanced diffusion (TED) has been found in Pt/Ti bilayers which can be induced by low-energy ion-sputtering. TED usually occurs in semiconductor crystals when diffusion is augmented by nonequilibrium conditions and it used to be attributed to the enrichment of vacancy concentration. The ion-sputtering induced intermixing has been studied by Monte-Carlo TRIM, molecular dynamics (MD) simulations, and Auger Electron Spectroscopy depth profiling (AES-DP) analysis in Pt/Ti/Si substrate (Pt/Ti) and Ta/Ti/Pt/Si substrate (Ti/Pt) multilayers.
In Ti/Pt we get a much weaker interdiffusion (broadening at the interface) than in Pt/Ti (see the AES-DPs in Fig. 3). We are able to capture the essential features of

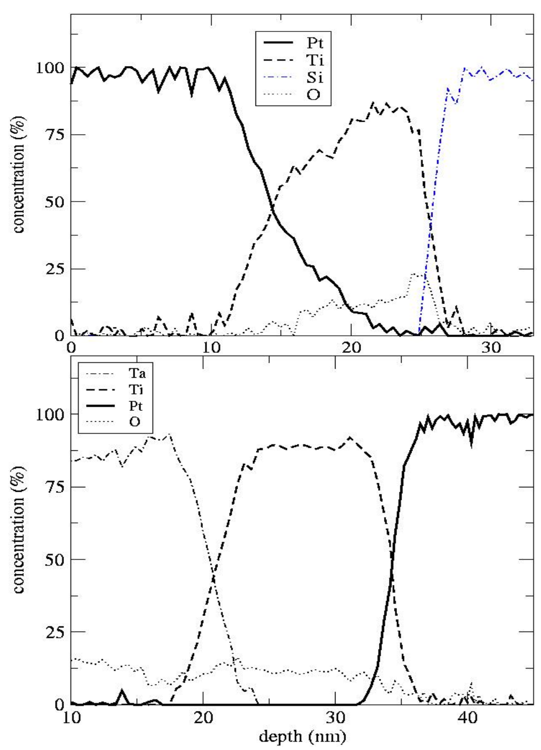


Fig. 3

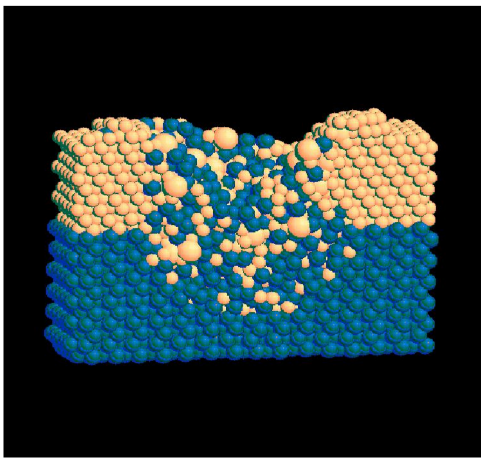


Fig. 4

intermixing using TRIM and MD simulations for ion-beam sputtering and get reasonable values for interface broadening which can be compared with the experimental measurements.

We explain the asymmetry of intermixing by the possible occurrence of transient enhanced diffusion in Pt/Ti which manifests in the long diffusity tail of the AES-DP concentration profile. On the contrary, the AES-DP of Ti/Pt seems to be "normal". The square of atomic displacements at Pt/Ti shows nonlinear scaling, which suggests anomalous mixing mechanism. In the Ti/Pt system linear scaling has been found. Pt/Ti shows an enhanced broadening in agreement with the measurements. The snapshot of the strongly intermixed final configuration as a cross-sectional view for the Pt/Ti system after 100 ion irradiation steps is shown in Fig. 4.

(For details, see published: P. Süle, M. Menyhárd, L. Kótis, J. Lábár, W. F. Egelhoff Jr.: Asymmetric transient enhanced intermixing in Pt/Ti, Journal of Applied Physics **101** 043502 (2007))

Sputtering yield measurements

(NKFP 3A/071/2004, SLO 14/03)

Árpád BARNA, László KÓTIS, Miklós MENYHÁRD, A. ZALAR, P. PANJAN

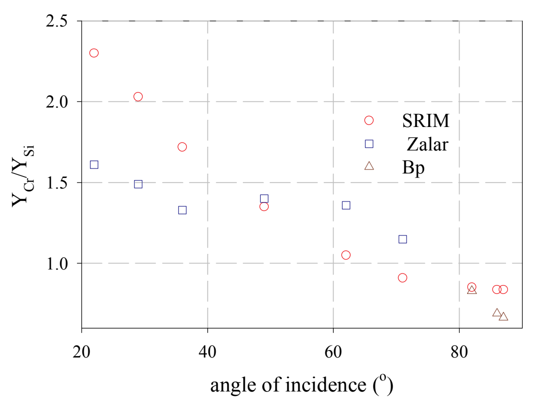


Fig. 5

For the various applications of ion sputtering the knowledge of the sputtering yield is necessary, therefore we measured the relative sputtering yield for various materials. Fig. 5 shows the Cr to Si relative sputtering yield vs. the angle of incidence of the bombarding Ar^+ beam with the energy of 1 keV. The data in the angular range of 22-75° were measured in Ljubljana, while the remaining values have been determined in Budapest. The corresponding results predicted by SRIM calculations are also shown.

It is clear that the deviations between the measured and calculated values are considerable, and therefore the experimental checking of the sputtering yields is unavoidable.

(For details see in print: L. Kótis, M. Menyhárd, L. Tóth, A. Zalar, P. Panjan: Determination of relative sputtering yield of Cr/Si, Vacuum (2007)).

Development of generally usable ion gun

(NKFP 3A/071/2004)

Árpád BARNA, Miklós MENYHÁRD, György RADNÓCZI, Zsolt CZIGÁNY, Technoorg Linda Ltd.

The development of the generally usable ion gun, together with Technoorg Linda Ltd., has been continued. We succeeded to built the small size low energy gun, see Fig. 6. The gun is mounted to a CF 40 flange, which gives good chance to apply in any usual vacuum chambre. The manipulator allows x-y transition, and tilting is also possible. The gun has been tested and proved to be satisfactory.

The prototype of the 20 keV ion gun has also been built. Moreover, the new vacuum chambre housing both the low and high energy ion gun has been constructed. In this system there is a load-lock possibility, which improves considerably the vacuum conditions. In the new system called IV 7/2 both ion guns, sample manipulation, rotations, etc, are fully computer controlled. The image of the system is shown in Fig. 7.

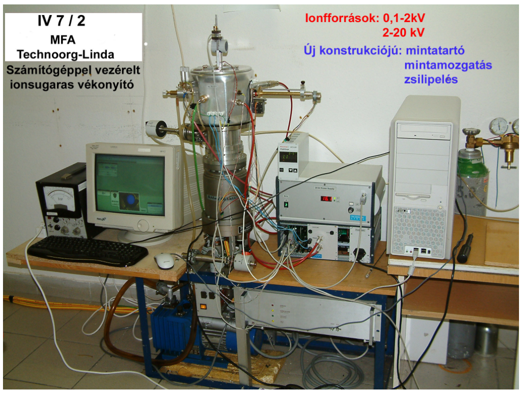


Fig. 6

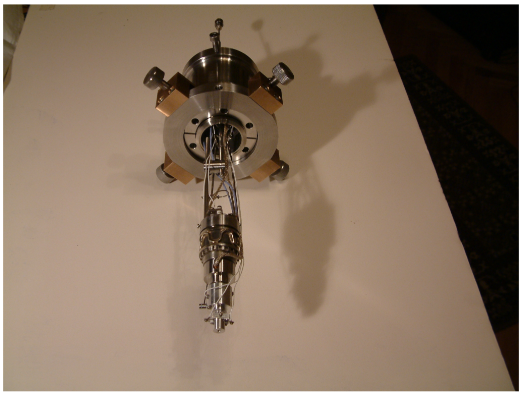


Fig. 7

Thin Film Physics Laboratory

Hybrid Substrates for Mass Production of High Frequency Electronics, HYPHEN

(FP6 IST 027455, Coordinator: PICOGIGA, France)

Béla PÉCZ, Lajos TÓTH, László DOBOS, Ferenc RIESZ, György Z. RADNÓCZI

The goal of the project is the development of hybrid substrates for GaN growth. Polycrystalline SiC is used as the starting material. About 500 nm thick single crystalline Si, or SiC layer is transferred onto the starting wafer by smart-cut and wafer bonding process (PICOGIGA). MFA does overall characterisation of the above hybrid substrates and epitaxial layers grown by MBE and CVD methods. Wafer bow is determined by Makyoh topography. The layers, interfaces are characterised by transmission electron microscopy and dislocation density is determined as well.

The results achieved up to now are the following: The starting material has a columnar grain structure. Defects in the Si and SiC layers transferred by smart cut and wafer bonding were not detected. The top surface of the hybrid substrate is a bit wavy due to the smart cut process. However, the surface of the HEMT layers grown by MBE onto the above hybrid substrates (single crystalline Si/SiO_2/polycrystalline SiC) is already flat. The same orientational relationships are determined, as in the case of GaN grown onto thick Si wafer. Dislocation density in the near surface region is 7-7.5×10^9 cm^{-2}. Our investigations proved that the nitride layers grown onto hybrid substrates are as good as the reference layers grown onto thick, classical wafers. The main benefit of the process will be realised in hybrid wafers with thin hexagonal layers.

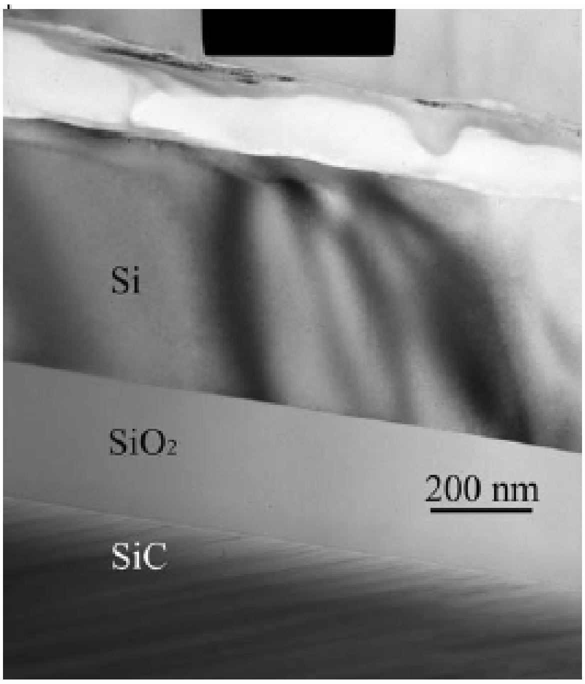


Fig. 1 *Cross section of a typical hybrid substrate prepared by smart-cut and wafer bonding. The base material is polycrystalline SiC. The strip of single crystalline Si (with an oxide layer) is transferred onto the starting material by wafer bonding.*

Nanocomposites for Piston/Liner Systems

(EU-FP6 NMP3-CT-2003-505622)

Béla PÉCZ, Lajos TÓTH, Éva HEGEDŰS, István KOVÁCS

Nanocomoposite coatings are extensively investigated in the last couple of years for their advantageous mechanical and tribological properties. The self lubricating metal and ceramic nanocomposite coatings (the subject of this project) are layers composed of a matrix with low friction and of metallic particles dispersed in the matrix. Tungsten, chromium, or their carbides, nitrides may be applied in coatings on piston rings, while the solid lubricating material can be graphite, MoS_2, or h-BN.

MFA is responsible for the structural characterization of the new coatings in the NAPILIS project, which is mainly done by transmission electron microscopy. A few possible coatings are under development in the project.

Cr-B-N coating layers were sputtered by reactive sputtering from a CrB_2 target onto Si (001) substrate at the University of Leoben. One of the most important parameters studied is the nitrogen content of the sputtering gas ($Ar-N_2$). The coatings prepared at low nitrogen content (9% N_2) exhibit a columnar, polycrystalline structure. Hexagonal CrB_2 (JCPDS 34-0369) phase was determined by electron diffraction in the above coating. Increasing the nitrogen content (23% N_2) the average crystallite size decreases below 1 nm, but a fine structure with two components can be observed clearly (see Fig. 2). In the case of high nitrogen content (68% N_2) the deposited layer contains high number of cubic CrN crystallites. The amorphous matrix containing the nanocrystals is BN, as that is proved on the high resolution and energy filtered images. The goal of the project is the development of a coating, what is hard enough and same time its friction coefficient is low.

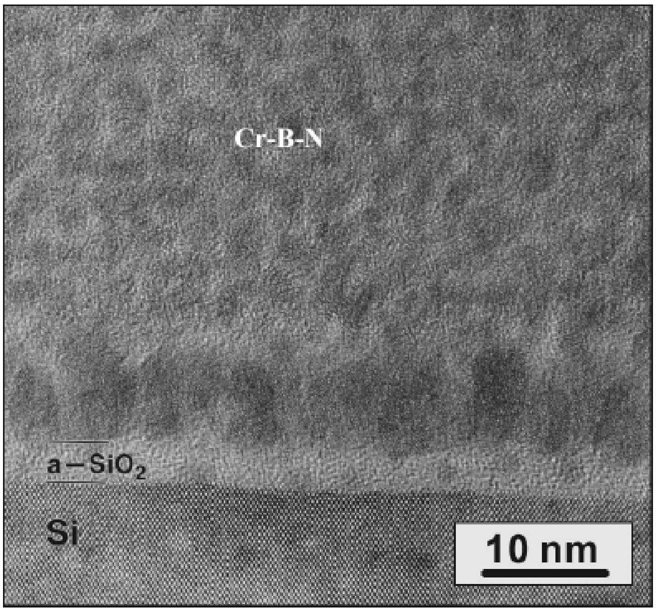


Fig. 2 High resolution micrograph showing two-phase microstructure.

Beside the Cr-B-N layers there are two further candidates studied for that purpose. Both of them are composed of CrC-amorphous C, but their depositions as well as morphology are very different. One of them is prepared by the reactive sputtering of Cr (in methane/Ar gas), what results in the formation of fcc CrC grains dispersed in amorphous carbon matrix. The average grain size is about 5 nm. Although the distribution of the grains in the matrix is random, a quasi-periodic arrangement can be observed, which is formed by a self organizing process during the layer deposition. Another method is a hybrid process in which the components are deposited by arc deposition and results in a super lattice-like multilayer. The optimization and scale up of the last two methods are in progress.

Investigation of the structural order in layered structures

(Hungarian Scientific Research Fund under Grant No. PF 63973)

Viktória KOVÁCS KIS, János LÁBÁR, Csanád SAJGÓ, Mihály PÓSFAI

The term 'soot' is used for carbonaceous particles that are produced by the combustion of fossil fuels or vegetation, and have characteristic morphology, size and microstructure (Fig. 3). As the strongest absorbent of shortwave radiation in the atmosphere, soot (or 'black carbon') has a strong influence on the radiation balance of the Earth. The term 'black carbon' is frequently used to emphasize the absorption properties of carbonaceous material. Black carbon is considered to be a mixture of "graphite-like", elementary carbon and light-absorbing organic matter. While bulk spectroscopic measurements are made on this mixture black carbon, in the TEM the components are clearly identifiable.

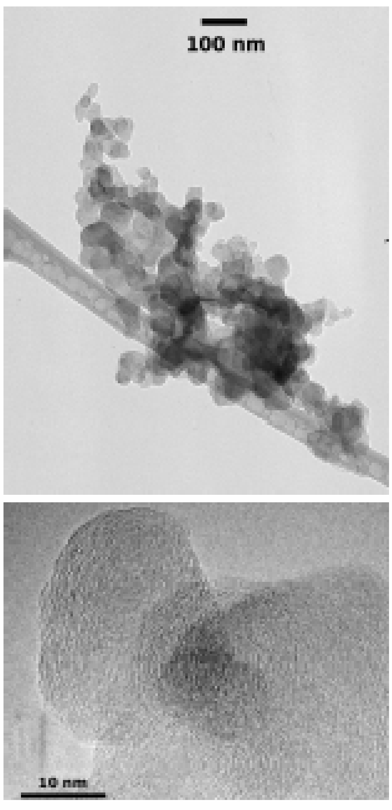


Fig. 3 *The microstructure (top),and the onion-like nanostructure (bottom) of shoot particles.*

In order to be able to assess the optical properties of atmospheric soot, detailed information on its structure is required. The widely accepted structural model for soot assumes the presence of graphene sheets that consist of a net of hexagons formed by carbon atoms, as in graphite. The stacking of concentrically wrapped, curved graphene sheets results in a typical onion-like structure (Fig. 3). However, it has long been known from bulk spectroscopic studies that black carbon and soot formation involves the growth of layers from aromatic rings, and that soot contains other elements besides carbon.

We studied the structure of atmospheric soot using electron-diffraction-based pair distribution function (PDF) analysis, and compared it with other carbon structures. Two reference materials were used to reveal aromatic moiety in soot particles: a hydrogen-free and a hydrogen-containing one.

(1) Magnetron-sputtered amorphous carbon, which was produced on NaCl substrate in Ar atmosphere at room temperature, under a pressure of 107 mbar. The thickness of the amorphous carbon samples ranged between 0.5 and 40 nm.

A kerogen (= insoluble organic matter, for detailed explanation see e.g. Oberlin et al 1980) sample with a H/C ratio of 0.61 which bulk composition is close to that of soot. First-neighbour atomic distances (L1) in atmospheric soot are as small as 0.134 nm, much shorter than in graphite (0.142 nm) or in amorphous carbon (0.141–143 nm), but larger than the typical value (0.131–0.132 nm) for the studied kerogen. These results suggest that a high molar ratio of hydrogen is present in soot in small-sized aromatic clusters (Fig. 4).

The hydrogen content of amorphous carbon affects the low-loss part of the EEL spectrum as well. The incorporation of up to 30% hydrogen reduces the plasmon energy of amorphous carbon by 2 eV from its typical value of 24 eV (Chen et al., 2005; Calliari et al., 2006). In order to determine the hydrogen content of atmospheric soot, we performed EEL measurements on one of our soot samples. The plasmon peak was found to be present at 22.2 eV, which is consistent with literature data for hydrogen-bearing amorphous carbon and suggests the presence of hydrogen in the measured atmospheric soot (Fig. 5). For further details see also Ref. [85].

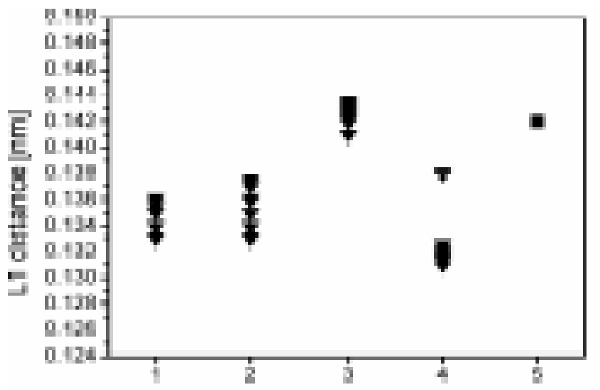


Fig. 4 *x-axis: 1 – soot 1 from Central Europe, 2 – soot 2 from South Africa, 3 – magnetron sputtered amorphous carbon (H/C = 0), 4 – kerogen with 95 at% total carbon (H/C = 0.61), 5 – graphite, not measured*

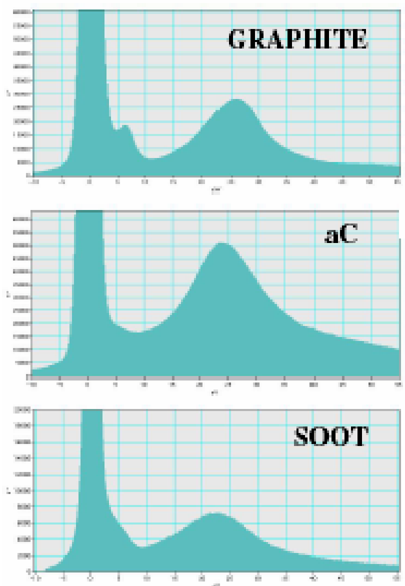


Fig. 5 *EELS measurement: low mass region.*

HAS SUPPORT TO EU PROJECTS (period 2006)

SPECIAL NANOSTRUCTURED COATINGS

Project leader: Dr. György RADNÓCZI

The Thin Film Physics group was very successful in applying for support in the EU 6th framework program, and takes part as participant in two IP and one STREP projects, working on special multifunctional hard and antifriction coatings. These projects are the utilization of both thin film and electron microscopy knowledge, accumulated in the research group for decades. In addition, a FP5 project on „New fullerene-like materials" was also included. The obtained support of 11.109 million HUF was mainly used for the recovery and renewal of the infrastructure, the maintenance and running cost of expensive analytical tools (two electron microscopes), spare parts and materials, education and library costs.

The supported EU projects:

- **INNOVATIAL** EU project IP 515844-21, Innovative processes and materials to synthesise knowledge-based ultra performance nanostructured PVD thin films on gamma titanium aluminides
- **NAPILIS**, EU-FP6 NMP3-CT-2003-505622 (Nanocomposites for Piston/Liner Systems)
- **FULLMAT** (New Fullerene like materials, HPRN CT-2002-00209) +
- **FOREMOST** (FOREMOST NMP3-CT-2001-515840 "Fullerene based Opportunities for Robust Engineering: Making Optimised Surfaces for Tribology"):

New Fullerene-like Materials (FULLMAT)

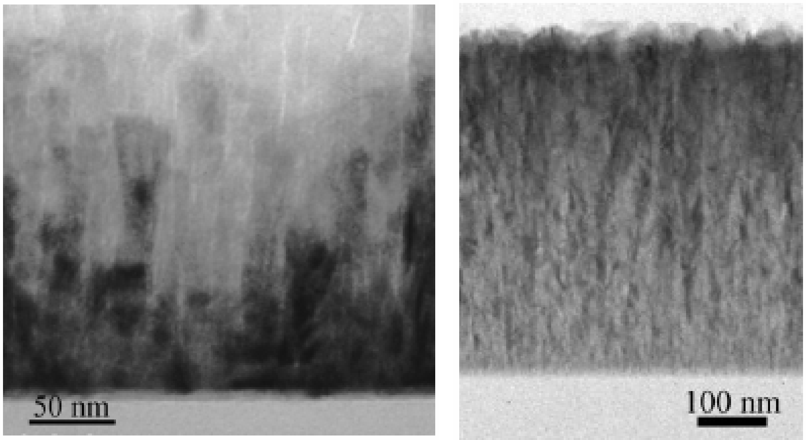
(EU5, HPRN-CT-2002-00209 (202-2006))

György RADNÓCZI, Zsolt CZIGÁNY, Katarína SEDLÁCKOVÁ, Róbert GRASIN, György KOVÁCS

Nanocomposite coatings composed of crystalline and amorphous nanophase mixtures have recently attracted increasing interest with respect to industrial applications. More generally, the use of carbon – metal composite films is aimed to ensure a good adhesion of the films to different substrates, to increase their hardness, modulus of elasticity and improve their wear properties. For all applications and scientific questions, characterization of the films on nanometer scale is essential. The reproducibility of the structure and properties of the films is always a key point.

C-metal (Ni, Ti) nanocomposite thin films were deposited by dc magnetron sputtering in argon between 25°C and 800°C onto SiO_2 (300 nm) covered Si substrates. Correlation was found between structure and mechanical properties of C-metal (Ni, Ti) films.

The studies of these films showed that the high hardness and elasticity are consequences of columnar structure and the graphite-like



(a) **(b)**

Fig. 6 *Cross section TEM images of C-metal nanocomposite thin films prepared at 200°C. a) C – Ni film, b) C – Ti film.*

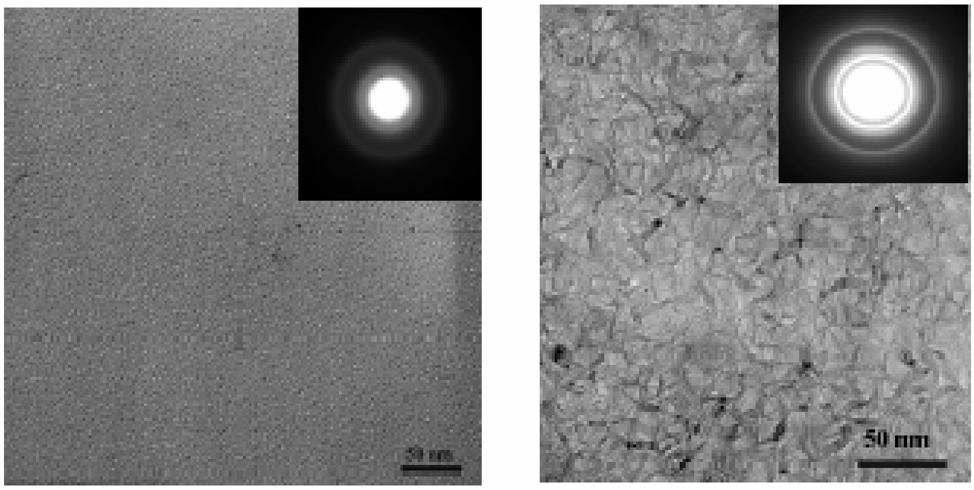
amorphous carbon phase in the matrix. The best mechanical properties (highest hardness and highest modulus of elasticity) were observed in the films of columnar Ni_3C and TiC crystallites, with column length practically equal to the film thickness, separated by carbon matrix. The carbon matrix consisted of disordered and ordered graphite-like carbon phase.

The H/E ratio of 0.1 and elastic recovery of 0.5 indicate that the deformations of the films arise mainly from deformation of the matrix which determines the elasticity of the asperities in a tribological contact. As it was shown on film series prepared at low deposition temperature (25°C and 200°C) at various power of Ni target, the hardness of films was independent of Ni content in nanocomposite, suggesting an interface sliding deformation mechanism. On the contrary, the Young modulus shows a linear dependence on Ni content of the films corresponding to the rule of mixtures. The C-Ti nanocomposite thin films showed the same results.

Projects FULLMAT and FOREMOST

The results of the last year in the FULLMAT project can be divided into two main topics. The first one is related to the study of local structural order by electron diffraction in different types of disordered carbons. The second main topic is about the carbon based nanocomposites where the metal components were Ni and Ti.

Structural differences of amorphous and FL components (nanotubes) are compared to glassy carbon, a material between amorphous carbon and graphite. The short and medium range order measured by the Fourier transformation of the diffraction intensity distributions is compared for carbon structures. Selected area electron diffraction (SAED) patterns were recorded on a Philips CM 20 – TEM operating at 200 kV accelerating voltage using DITABIS imaging plates. This image is processed with the Process Diffraction program. The Q(i)Q reduced interference function and its Fourier transform, the pair correlation function (G(r)) was determined by applying a

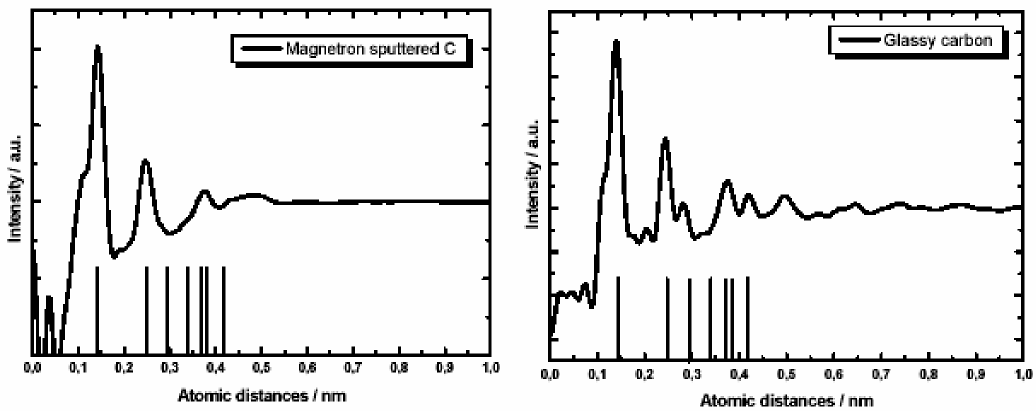


(a) Amorphous PVD carbon **(b)** Glassy carbon

Fig. 7 *BF-TEM images of the studied materials and their diffraction patterns*

self consistent empirical correction to the baseline of the measured diffraction, ensuring that the pair correlation function becomes physically meaningful. From the normalized pair correlation function (g(r)) we can determine the distribution of the atomic distances in the material. The coordination numbers can also be obtained from G(r). Using these techniques we studied an amorphous carbon film (Fig. 7 (a)) and also the connecting tissue of the metal-carbon nanocomposites, and a glassy carbon as reference. The image of the ion milled glassy carbon is presented in Fig. 7 (b). Glassy carbon is a turbostratic (disordered layer stacking) form of carbon that is produced by carbonizing a polymer under carefully controlled conditions of temperature and pressure.

We show similarities and also differences in g(r) of the two materials. These functions are presented as follows: in Fig. 8 (a) is the g(r) of the PVD carbon and Fig. 8 (b) shows the g(r) of the glassy carbon. Comparing the



(a) g(r) of PVD carbon **(b)** g(r) of glassy carbon

Fig. 8 *Normalized pair correlation functions of the studied materials, bars indicate the interatomic distances of graphite.*

g(r) functions of the glassy carbon and the g(r) function of the amorphous carbon we show that the glassy carbon has a higher structural order than the amorphous carbon. In case of the magnetron sputtered carbon a short range order is present up to 0.4 nm. The glassy carbon is more ordered and it shows a medium range order up to 0.7 nm. The first three nearest neighbours are almost identical with those of graphite. These distances are r_{1g} = 1.42 Å (r_{1gc} = 1.41 Å), r_{2g} = 2,46 Å (r_{2gc} = 2,44 Å) and r_{3g} = 2.84 Å (r_{3gc} = 2.83 Å) representing the nearest neighbour distances in the hexagonal ring of a graphene sheet. The fourth nearest neighbour distance r_{4g} = 3.35 Å, which corresponds to the interlayer distance in graphite, is shifted towards larger atomic distances in glassy carbon and in amorphous carbon as well (r_{4gc} = 3.73 Å, r_{4ac} = 3.75 Å). This shift can be related to curve geometry of the graphene sheets.

C-Ti thin films were prepared by simultaneous dc magnetron co-sputtering of Ti and C at various deposition temperatures (25 to 800°C). All the films (except of that prepared at 800°C) consisted of TiC columns 10-100 nm wide that were embedded in a partially ordered or disordered carbon matrix. The thickness of the carbon matrix between adjacent TiC columns was ~ 2-5 nm. Mechanical properties of C-Ti films strongly depended on the deposition temperature. The H/E ratio of C-Ti nanocomposites is between 0.052 and 0.086 and the elastic recovery parameter is 0.25 and 0.47. Films deposited at 200°C had the highest hardness H ~18 GPa, the highest reduced modulus of elasticity E ~ 210 GPa and the highest TCR (temperature coefficient of electrical resistivity) value ~ 0.0011 K^{-1}.

Results of structural and mechanical properties of C-Ti nanocomposite thin films are similar to that of C-Ni nanocomposites. The hardness of C-Ni and C-Ti films is not influenced by the Ni or Ti content. With increasing metal content from 9 to 50 at.%, the hardness of films remained practically constant. This observation supports also the statement, that the hardness of the studied C-Ni and C-Ti films is determined by the hardness of the carbon matrix. The thin carbon matrix (2-3 nm) which isolates the columnar crystallites consists of disordered and graphite-like carbon.

Ion beam assisted deposition (IBAD) of Ni-C nanocomposites was carried out in collaboration with the laboratory from Dresden (Germany). TEM and HREM characterisation of a:C-Ni samples prepared at 25 – 500 °C grown in Dresden has been carried out in Budapest. These 20 nm thin films consisted of amorphous carbon matrix and columnar Ni_3C nanocrystals. DC sputtered and IBAD prepared films have essential structural similarities. Publication of results and further investigations are in progress.

Hungarian Scientific Research Fund under Grant No. 048699

Péter BARNA, György RADNÓCZI, Fanni MISJÁK, Marianna SZERENCSI

There is increasing scientific and commercial interest in the development of nanostructured thin films due to their outstanding properties relative to single-phase materials. Several reports on ceramic-ceramic or ceramic-metal nanocomposites are found in the literature, while less examination studies the properties of metal-metal nanocomposites.

Ceramic films possess ultrahigh hardness. However, this high hardness is usually accompanied by low fracture toughness and inadequate ductility. These properties can cause failure of the film when applied on deformable substrates. On soft and deformable substrates vapour-deposited thin metal-metal composite films represent a potential solution for appropriate coatings as has been demonstrated by bearing designers and polymer tribologists as well as in some biological applications.

The Cu-Ag system can be a suitable model for the investigation of structure development in metal-metal nanocomposites and their structure-property relations. Cu-Ag films have been the subject of investigation in many works for they are used as contacts and interconnect layers in semiconductor industry and on plastics where both mechanical and electrical properties are important. Metal-metal nanocomposites are studied to answer the questions of their formation mechanism, morphological development and related physical properties.

The films were prepared by combinatorial co-deposition of Cu and Ag in a wide composition interval using thermal evaporation in high vacuum. Films close in composition to the eutectic have grain size below 10 nm and display strong <111> texture. Nanoindentation data show that Cu-Ag nanocomposite films have a maximum of hardness reaching 4 GPa around 20 at% of Ag, four times greater than either of the building components. The composition dependence of the Young modulus obeys the rule of mixtures, while their H/E ratio values are about 0.02 and practically constant in the 10-60 at % Ag content range.

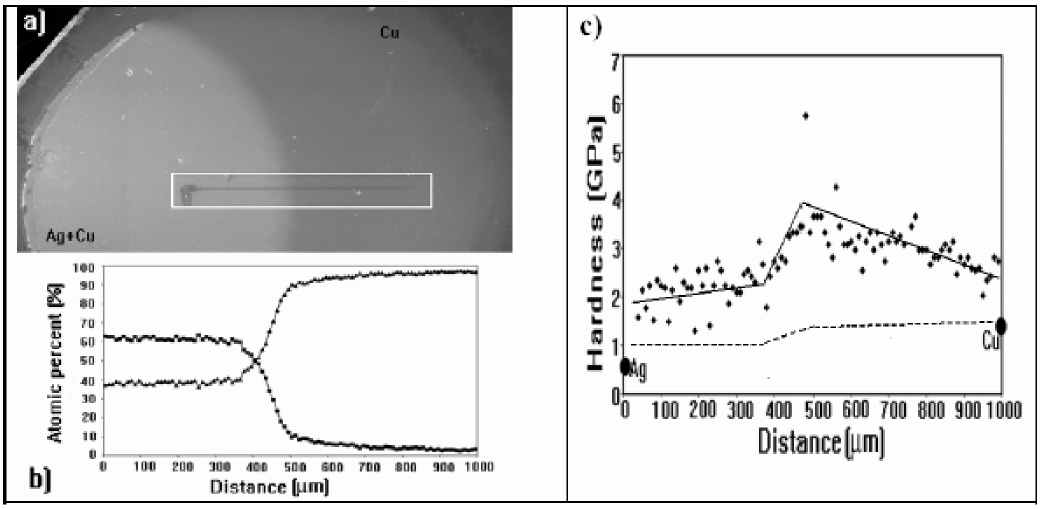


Fig. 9 *Combinatorial sample of a Cu-Ag two component film (a) and its compositional distribution (b) as measured by X-ray microanalysis in SEM. The composition dependence of the hardness (c) of combinatorial sample shown in (a). The maximum corresponds to 20 at % of Ag in the sample. The dotted line in (c) depicts the hardness, corresponding to the rule of mixtures.*

DEVELOPMENT OF IV7 ION MILLING EQUIPMENT

(GVOP-3.1.1.-2004-05-0495/3.0)

György RADNÓCZI, Péter BARNA, Zsolt CZIGÁNY, Andrea JAKAB, László PUSKÁS, Árpádné BARNA, Technoorg Linda Ltd.

Two ion guns were built in the prototype system of Technoorg Linda models IV (Ionmiller) series into the IV3 and IV4 vacuum chamber models, a 20kV gun and a low energy (150V-2kV) gun. However, contrary to the older models, in the prototype the ion guns were in fixed position. The turbo-pumped system, with the attached load lock system had a final vacuum of ~10^{-7} mbar.

Measurement of the milling rate

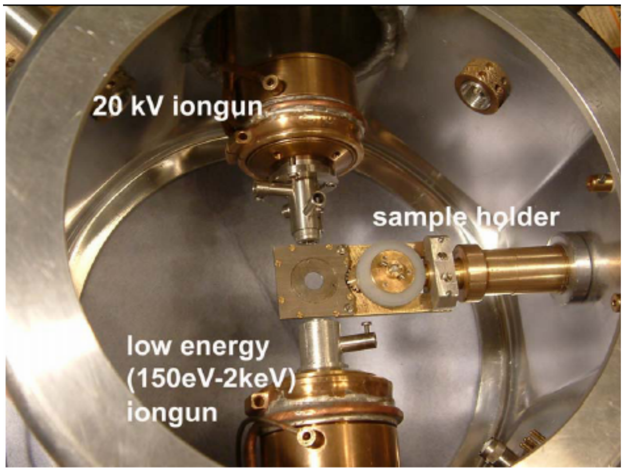


Fig. 10 *IV7 system prototype: the low and high energy guns in the vacuum system.*

The milling rate was measuerd on Si and WC samples which were mechanically thinned to defined thickness and milled until perforation. Si is one of the most often used sample or substrate material, WC is a hard material aslo from ion milling point of view. Both materials are stable against ion impcat at the energies used. The thicknesses of the Si and WC test samples were 15 μm and 10 μm, respectively. The 20 kV gun had 3 times higher milling rate than the conventional TELETWIN gun (at 10 kV).

Surface amorphization of Si single crystal

For the determination of the depth of surface amorphization the technique described in: Á. Barna, B. Pécz, M. Menyhárd, Ultramicroscopy **70** 161-171 (1998) was used. In the HREM images it is visible that the thickness of the amorphous region is about 12 nm (see Fig. 11). This in accordance to the expectation, extrapolated from measurements at lower energies (~1nm at 250V, ~5 nm at 3kV ion energy). To a good approximation, the impact depth is proportional to the square root of the ion energy.

Computer controlled operation

The controlled parameters are: the angle of ion beam to the milled surface, rotation or rocking of the sample, the rate and angular interval of these, accelerating voltage of ion guns, focusing and other auxiliary voltages of the guns. The unit was used in the computer controlled mode for the test measurements.

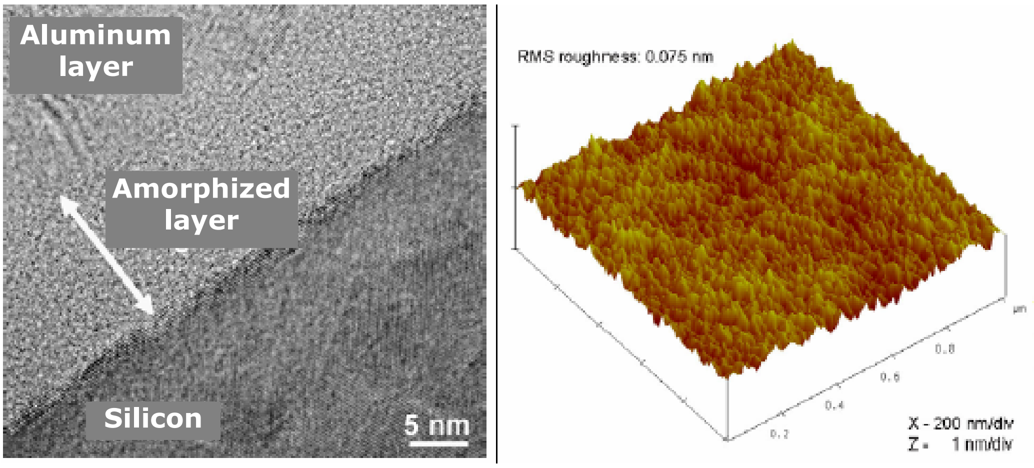


Fig. 11 *Cross section HREM image of a Si single crystal, ion milled by 20kV Ar^{+} ions (left) and the AFM image of its surface (right).*

Load lock system for ultra vacuum sputtering unit

(GVOP-3.2.1.-2004-04-0353/3.0)

Zsolt CZIGÁNY, György RADNÓCZI, György Zoltán RADNÓCZI, László PUSKÁS

A new heating stage and load lock has been purchased for the DC magnetron sputtering unit (see Figs. 12 and 13). The rotating heating stage operates up to 850 °C and can host samples up to ∅ 3″ diameter in size. It makes possible the preparation of combinatorial samples due to its size and different distances to the two magnetrons. The quartz lamp heating makes possible reactive sputtering in oxygen as well.

The installation of the load lock system ensures easy sample change maintaining the close UHV (10^{-8}) mbar) base pressure.

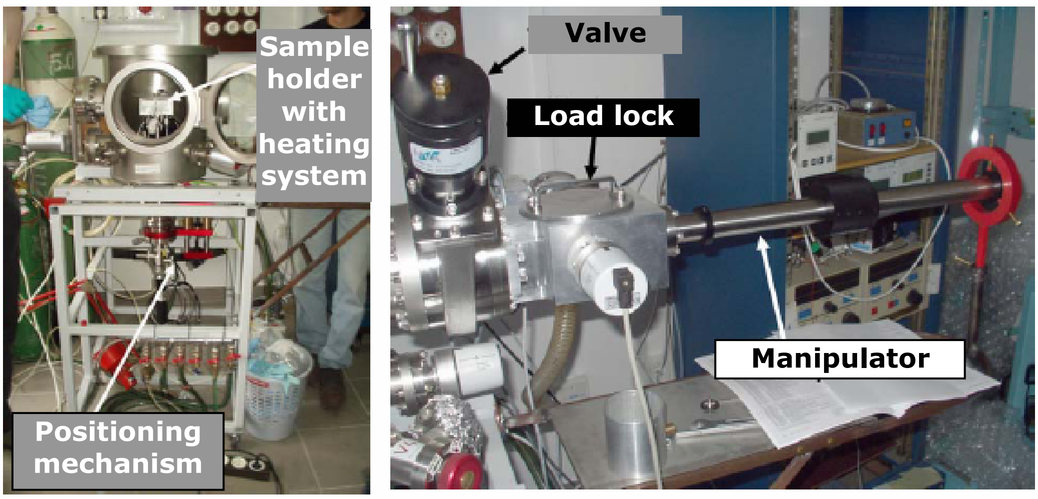


Fig. 12 *The magnetron sputtering unit with the heating stage (left) and load lock (right) being installed.*

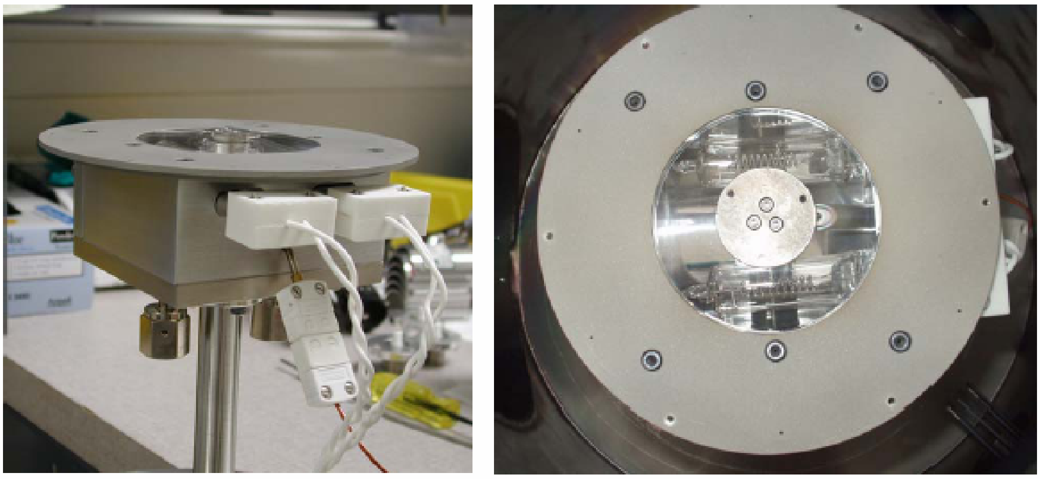


Fig. 13 *Side and top view of the heating stage.*

Improvement of organic LEDs (OLED) performance

György SÁFRÁN, Olga GESZTI, Péter SOÓS, Prof. Tou Teck YONG*, T. K. YONG*
S. S. YAP*
**Multimedia University, Selangor, Malaysia*

Thin films of indium-tin oxide (ITO) are used as the transparent and conducting electrode for flatpanel display, which has included the organic light-emitting device (OLED) in the last two decades.

There are several common methods for thin film deposition of ITO on different substrates including magnetron sputtering, spray pyrolysis, pulsed laser deposition with KrF or ArF excimer laser at λ= 248 nm, or 193 nm, respectively. ITO of commercial devices is generally deposited by the RF-sputtering technique.

In this project ITO was deposited by pulsed Nd:YAG laser deposition at 355 nm. A great deal of effort has been made to improve the performance and increase the stability of the OLED devices, and relatively, more attentions were paid to the interfacial phenomena between the ITO and the organic layer. These issues include poor contact, oxidation of organic layer by ITO ion diffusion from ITO, and the energy barrier. All these required some forms of surface modification of ITO which enhanced OLED performance, for example the reduction of surface roughness, introduction of an interface layer and oxygen plasma cleaning of ITO surface.

In this project the coating of ITO surface by a thin diamond-like carbon (DLC) interface layer has also been investigated for better performance and reliability of OLED. MFA carried out the TEM and EELS spectral analysis of the ITO and DLC layers. Substrate heating at 250 ºC decreased the ITO resistivity by almost an order of magnitude to about $3x10^{-4}$ Ωcm, while maintaining the optical transmission at more than 90% in the visible region (400–800 nm). The surface roughness of PLD-grown ITO

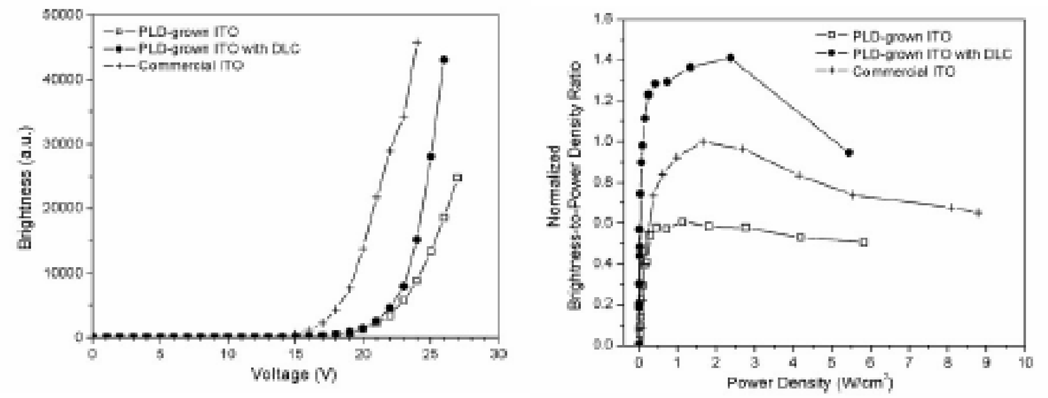


Fig. 14 *Comparison of OLED brightness charactertistic and performance as a function of operating voltage (left); and the normalized brightness-to-power density ratio characteristics as a function of input power density (right), using PLD-grown ITO with and without DLC and commercial ITO*

was probably the main factor which determined that OLED performance. The surface roughness of PLD-grown ITO was reduced by DLC coating, hence its OLED brightness was greatly improved as a result of reduction of many minute hot spots which could be observed with naked eyes.

Despite higher operating voltage and lower injection current, OLED based on DLC-on-ITO substrate was more efficient than that fabricated using the commercial ITO. OLED degradation, largely due to thermal effect, could be deduced from the plot of brightness versus the input power density. The first results provided a decrease of the ITO surface roughness and better deposition parameters for tuning of the DLC properties. The improved surface smoothness and interface layer coupling increased the lifetime and the efficiency of the OLEDs.

A TEM and EELS Study of the Microstructural Changes of Steel Wires During Cold Drawing

(Austrian Hungarian Action Foundation/Action Österreich Ungarn, OMAA/AÖU No. 63ÖU2)

György SÁFRÁN, Olga GESZTI, György KOVÁCS, Claude PRIOUL[a], C. MAURY[a], P. SCHATTSCHNEIDER[b], M. STÖGER-POLLACH[b], S. RUBINO[b]

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Cold drawing of eutectoid steel wires increases the mechanical strength for applications in tyre reinforcement, cables and suspension springs. At strain levels of 3.5 their strength (about 3GPa) approaches that of carbon fibres, furthermore they own the advantage of ductility. The increase of strength is explained by a refinement of the microstructure, while the mechanisms of the reduction of ductility during cold drawing are not completely understood.

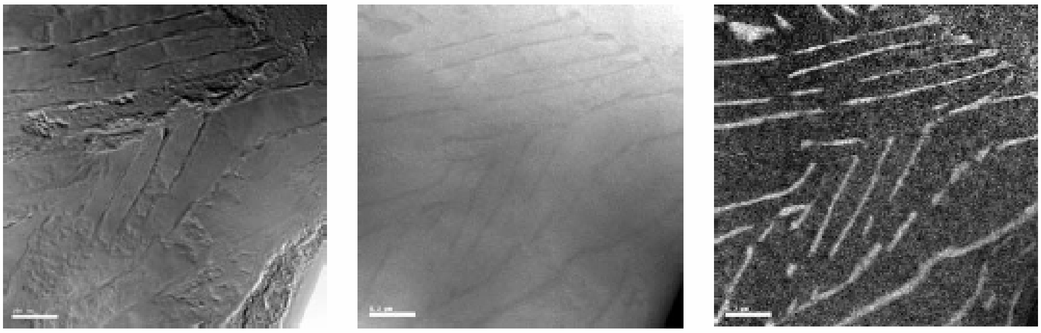

Fig. 15 *Energy filtered images- Zero loss image (left), Fe elemental map (middle) and C elemental map (right) - of a steel wire with pearlite structure.*

In the joint project, we investigated the microstructural changes of (0,82 C - 0,495 Mn) steel wires by transmission electron microscopy and electron energy loss spectrometry, due to cold drawing. One of the questions was the location of C in the lattice, in order to improve our models for the highly deformed steels. We are also interested in the arrangement of the dislocations in order to understand the mechanisms of plasticity at the nanoscale. The initial diameter of the studied wires was 1mm, which has been drawn to 0.291 mm with a strain level higher than 3 (tensile strength about 3 GPa).

A sample preparation method, including mechanical and ion beam techniques, was developed for cross- and longitudinal section TEM and EELS studies. The wire of initial microstructure builds up of 250-1000 nm size grains of pearlitic structure. It exhibits clearly arranged lamellae as alternating broad lamellae about 80 nm wide of ferrite (bcc iron) and narrow lamellae 15-20 nm wide of cementite (orthorhombic Fe_3C) as it was revealed by selected area electron diffraction and EELS elemental carbon mapping.

After drawing, the initial pearlitic structure turned to one with numerous voids and strong TEM contrast of incorporated high stress field. The contracted grains are about 40 nm wide and the corresponding elemental carbon map appears vague. These show that the plastic deformation during cold drawing results in grain refinement associated with high stress and void formation suggesting a strong influence on strength and ductility.

Thin Film Nanostructures Laboratory

Development and application of functionalized interfaces in specified biochemical and chemical systems

(NKFP 3/A 058-04/2004)

Gábor PETŐ, Albert KARACS, Tamás HORÁNYI, György MOLNÁR

It is well known that formation of different surface morphologies falling into the size range of 10 and 30 μm can enhance the bonding between the implant material and the cells. Moreover, size of the proteins that are adsorbed on the surface typically falls into the nanometer size range (10-30 nm) therefore a roughness with such a characteristic length can positively influence the process. On this way bioactive behaviour can be produced which results faster and stronger osseo-integration in medical practice.

In order to develop the nanometer- or sub-micrometer size morphology on the surfaces titanium disks were oxidized in a quartz vacuum oven at high temperature (400 °C) by the application of different small molecules (acetone, ethanol, formic-acid, water, oxygen) as oxygen sources. During this process titanium-dioxide layers have grown onto the surfaces, which were showed different wettability.

Changes in the bioactivity caused by the thermal oxidation were checked via SBF measurements (immersion into Simulated Body Fluid). The total amount and the composition of deposited Ca and P containing layer were identified by HR ICP-MS (High Resolution Inductively Coupled Plasma Mass Spectrometry). Larger amount suggests higher bioactivity. Table I summarizes the results of SBF measurements.

Oxidizing agent	Total amount of deposited Ca and P [mg]	Changes compared to the reference [%]	Ca/P mass ratio
Air (O_2)	0.7293	+4	-
Formic-acid	0.7752	+11	43.8
Distilled water	0.7749	+11	35.1
Acetone	0.7901	+13	35.8
Reference	**0.6970 (100%)**	**-**	**25.6**

Table I *Results of SBF measurements.*

Investigation of noise and electric parameters of quantum structures

(Hungarian-Greek S&T Cooperation program 2005-2006)

László DÓZSA, György MOLNÁR, Zsolt J. HORVÁTH, Zófia VÉRTESY

During deformation induced self-assembly two dimensional structures transform to three dimensional ones. Epitaxial silicide quantum dots may be potentially applicable for quantum cellular automata and for other quantum dot devices. The major motivation to the exploration of silicide quantum structures is the fact in particular that they will be compatible with silicon devices, which will probably remain useful as interfaces between nanoelectronics and the outside world.

β-$FeSi_2$ dots have direct band gap and can be grown epitaxially onto silicon, which is a semiconductor with indirect band gap. This system might be a potential material of optoelectronic, and nonvolatile memory applications in silicon-integrated technology.

Reactive deposition epitaxy method was used for iron-silicide nanostructure preparation, where the evaporated Fe particles arrive on a heated silicon substrate. The thicknesses of the starting iron layers were between 0.3 and 6 nm. The substrate temperature was 500ºC during evaporation and the samples were further annealed at 850ºC for 60 minutes.

Self-assembled, island- and wire-like, oriented β-$FeSi_2$, α-$FeSi_2$ and γ-$FeSi_2$ phases were found to grow on Si(001) substrates. The proportion of the desired β-$FeSi_2$ phase is enhanced with the thickness decreasing.

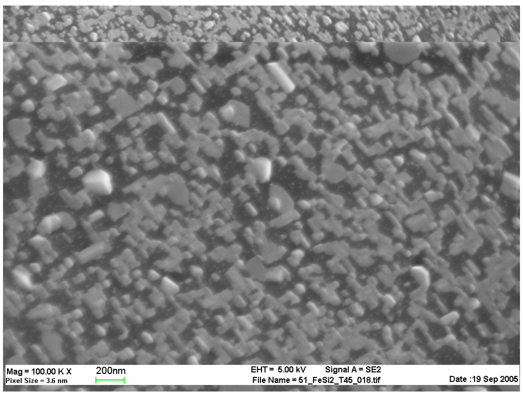

Fig. 1 *SEM image of iron-silicide nanostructures formed from 3nm Fe on Si(001)*

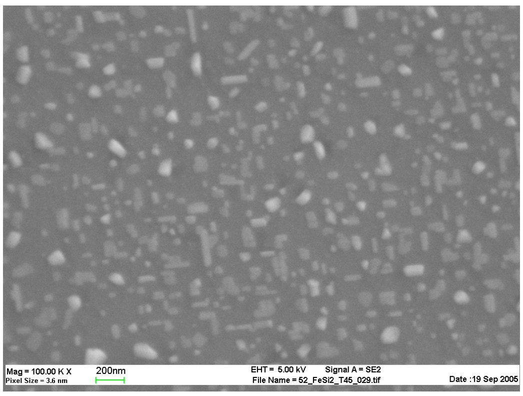

Fig. 2 *SEM image of iron-silicide nanostructures formed from 1nm Fe on Si(001)*

Nanoscale Morphology and Photoemission of Arsenic Implanted Germanium Films

(Cooperation with Chemical Research Center, Budapest)

Gábor PETŐ

Germanium films of 140 nm thickness deposited onto Si substrate were implanted with 70 keV arsenic ions with a dose of 2.5 x 10^{14} cm^{-2}. The morphology of As implanted film was dominated by nanosized (10-100 nm) Ge islands separated by empty bubbles at a depth of 20 to 50 nm under the surface. At depth ranges of 0 to 20 and 70 to a measured depth of 140 nm, however, morphology of the as-evaporated Ge film was not modified. At a depth of 20 to 50 nm, photoelectron spectra were similar to those obtained for Ge amorphized with heavy ion (Sb) implantation (Implantation Induced (I.I.) a-Ge). The depth profile of the morphology and the photoemission data indicate correlation between the morphology and valence band density of states of the ion I.I. a-Ge. As this regime was formed deep in the evaporated film, i.e. isolated from the environment, any contamination, etc. effect can be excluded. Depth distribution of this I.I. a-Ge layer shows that the atomic displacement process cannot account for its formation [127].

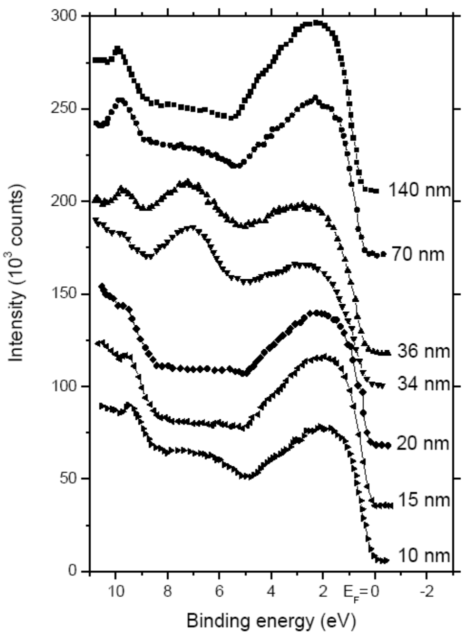

Fig. 3 *Energy distribution of photoelectrons (EDC) with different depths of As implanted Ge*

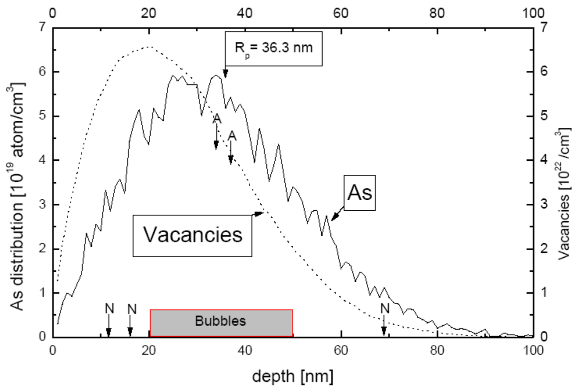

Fig. 4 *Depth distribution of vacancies (dotted line), and of As ions (solid line), as calculated by TRIM 92. The points N indicate the "normal" amorphous Ge, while points A show the regions I.I. a-Ge, respectively*

Microtechnology Department

MEMS Laboratory	Laboratory of Optoelectronic Devices	Semiconductor Characterization Laboratory
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MEMS Laboratory

Integrated micro-force sensor array

Mária ÁDÁM, István BÁRSONY, Csaba DÜCSŐ, Tibor MOHÁCSY, Gábor VÁSÁRHELYI, Éva VÁZSONYI

The major goal of the project was the integration of porous Si micromachining technique into conventional CMOS processing technology for fabrication of integrated tactile sensor chips. The demonstration device consists of 64 force sensing microelements, a CMOS decoder for addressing the sensors and p-channel MOS current generators (Fig. 1.). A patent pending describing the novel technology was filed with the national authorities. ("Integration of porous silicon micromachining process into conventional CMOS technology").

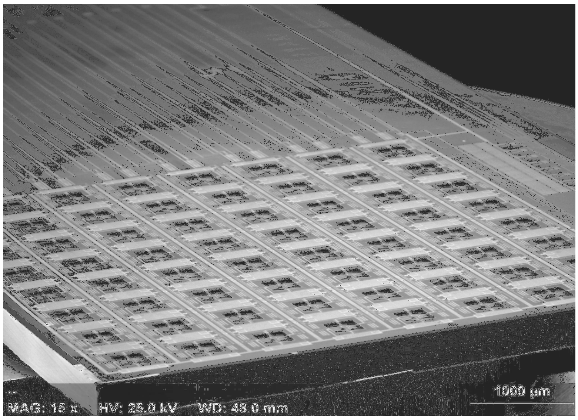


Fig. 1 *The 8x8 element CMOS integrated micro-force sensor array chip. The suspended sensing elements were formed by porous Si micromachining.*

In order to model human tactile sensing a mechanical structure similar to the fingertip was formed by covering the micro-force sensor array chip with 3D shaped elastomer. The elastomer has a double role: serves as a protective cover and also plays significant role in signal transduction, e.g. it modifies the signals and extends the sensing area called receptive field. The assembled chips, shown in Fig. 2, were functionally tested and applied in the demonstration tactile robotic-system constructed by the research group of Pázmány Péter Catholic University.

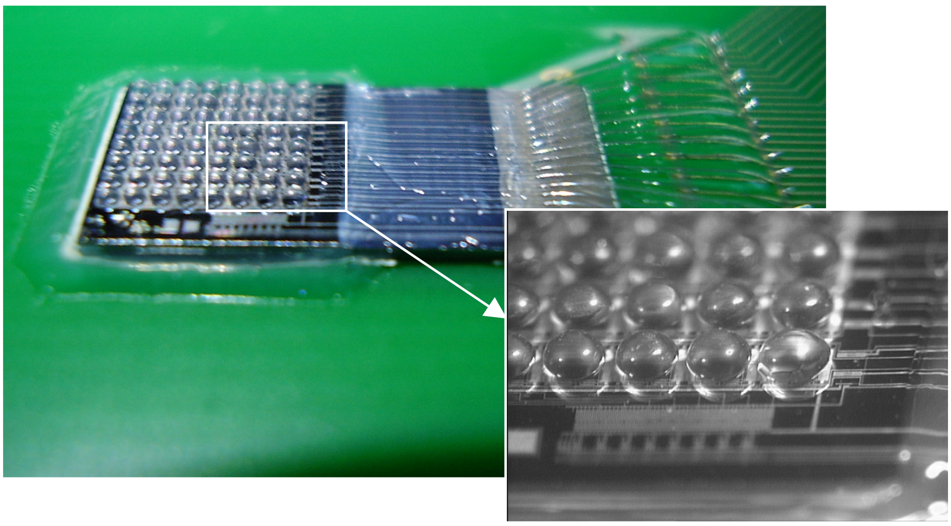


Fig. 2 *The tactile sensor chip covered with microformed elastomer*

Development of micro-fluidic elements with combination of membranes from porous Si multilayers

(Hungarian Scientific Research Fund under Grant No. T 047002)

Csaba DÜCSŐ, István RAJTA*
*Institute of Nuclear Research (ATOMKI), Debrecen, Hungary

Combined technology for the formation of microfluidic elements is being developed using proton micro-beam and porous Si micromachining. Due to the damages resulted by the deep proton implantation, the resistivity of the Si crystal becomes locally so high that it selectively impairs hole-current flow during electrochemical etching. Therefore, porous silicon is only selectively formed leaving c-Si 3D structures behind after its dissolution. The geometry of the 3D elements is determined by the implantation energy, the parameters of the proton micro-beam and the implantation dose. With a 2 MeV H^+ implant structures of 46 μm depth can be formed approximately.

The targeted demonstration device is a check valve for microfluidic application. A typical result is shown in Fig. 3.

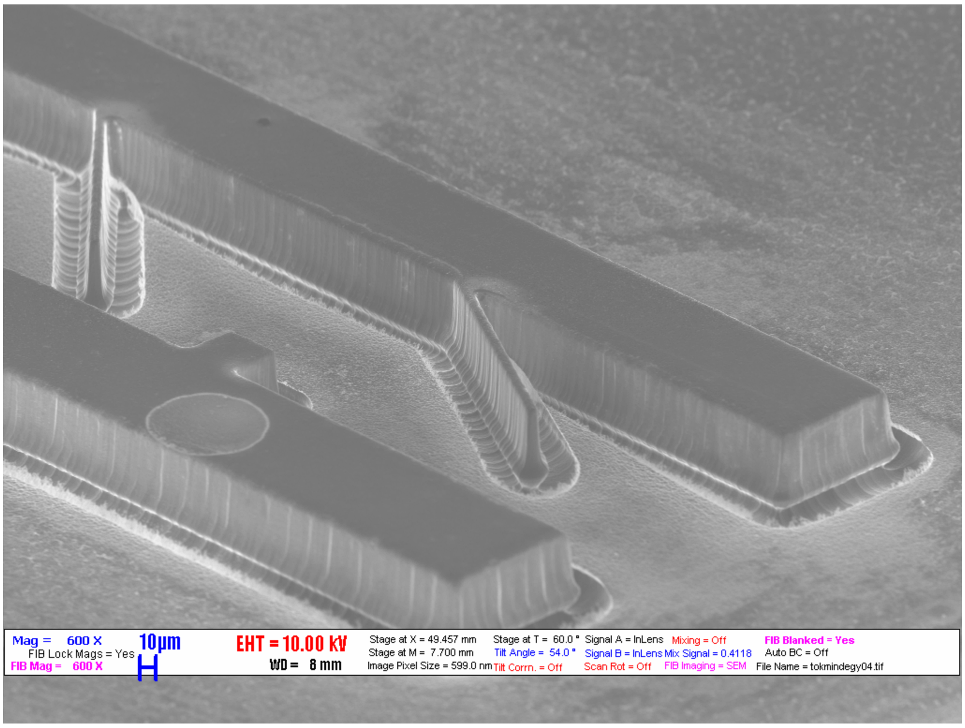


***Fig. 3** Test structure for the formation of Si check valve by proton microbeam implantation and porous Si micromachining*

Laboratory of Optoelectronic Devices

Solar Cell Innovation Center

(NKFP 3/025/2001)

István BÁRSONY, Zoltán LÁBADI, Ágoston NÉMETH, Sándor PÜSPÖKI, Vilmos RAKOVICS, Ákos NEMCSICS, István RÉTI, Béla SZENTPÁLI, Magdolna VARGA FERENCNÉ, Katalin VÖRÖS VERESNÉ

The overall aim of the project is to develop a thin film preparation system for R&D on solar cells with CuInGaSe active layer. The consortium went through a restructuring; the MTA MFA took over the leadership. The planed solar cell structure is shown in Fig. 1 below.

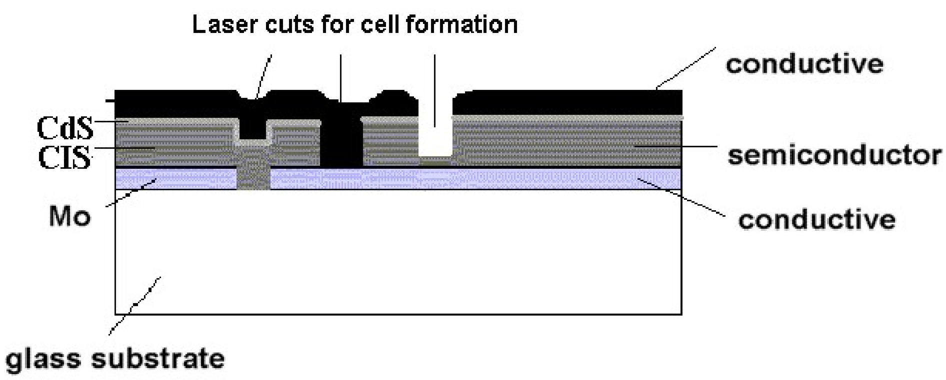


Fig. 1 *Scheme of a planed solar cell structure*

In 2006 the deposition of contact layers for CIGS solar cells was researched.

The purpose of the work is to develop an optimal technology for the deposition of transparent front contact layer for a CIGS solar cell. The structure consists of an undoped ZnO buffer layer and an Al doped conductive ZnO (ZAO) layer. The magnetron sputtering of the ZAO layer takes place from a Zn:Al (2% m/m) metallic target in $Ar:O_2$ atmosphere.

The technological parameters of the deposition of the ZAO layer have been studied, and the region where the suitable layer forms was established. In this technology the conductive and transparent ZnO film is deposited successfully at room temperature.

The layers are qualified by spectral transparency, sheet resistance. The specific resistance values are in the mOhmcm range.

Indoor light cell

Béla SZENTPÁLI, István PINTÉR, Edvárd KUTHI, Csaba DÜCSŐ, Mária ÁDÁM, Zoltán LÁBADI, Ágoston NÉMETH, Vilmos RAKOVICS, Tibor MOHÁCSY

The aim of the project is to develop „solar cells" optimised for indoor lighting, i.e. fluorescent light at about 700 lux intensity. The devices are planed to supply wireless indoor sensors. The project is cooperative; the partner is the Tsukuba Research Laboratory of Tateyama Kagaku Co. Ltd. (Tsukuba, Japan.).

The Plasma Immersion Ion Implantation (PIII) technology was applied for this task. This technology was developed in earlier years during the ADVOCATE (EU-FP6: ENK6-CT-2001-00562, 2001-2004) project. The PIII technique is a very low energy (100-1000 eV) implantation. It is used for Phosphorous doping of the emitter of Silicon solar cells. Due to the low energy implantation and the rapid thermal annealing the emitters are very shallow (0.2…0.3 μm). The shallow emitter and the properly designed antireflexion coating result in an enhanced efficiency at the bluish-white fluorescent light. Fig. 2 below shows comparison of the normalized efficiency of the indoor light cell structure (JBK7/1) and the usual Si solar cell.

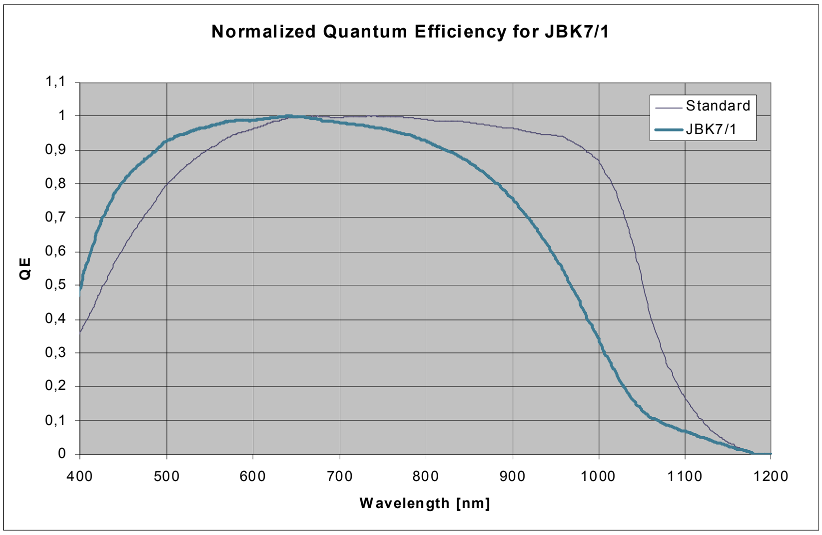


Fig. 2 *Normalized quantum efficiency of the indoor light cell structure (JBK7/1) and the usual Si solar cell.*

Solar simulator

(GVOP-3.2.1.-2004-04-0356)

Zoltán LÁBADI, Sándor PÜSPÖKI, Ákos NEMCSICS, István RÉTI, Béla SZENTPÁLI, Tamás BERKÓ, István MAKAI, János BALÁZS, Miklós RÁCZ, András HÁMORI

The project was sponsored by the Hungarian Ministry of Economy and Transport and aimed the installation a solar simulator system for testing and evaluation of different solar modules. The project is closely linked to the "Solar cell innovation center" project.

The equipment is a PVMT 11250 type continuous mode solar simulator (see Fig. 3) manufactured by the Energy Equipment Testing Service Ltd. (UK). It measures the current–voltage (I-V) characteristics of PV modules up to 1.5 m x 1.5 m area. The steady-state light is adjusted to the required intensity and is measured by a calibrated reference cell.

A computer based DAQ system acquires the module data and plots the I-V curve and displays a variety of module characteristics:

- Complete I-V curve
- Open-circuit voltage, V_{oc}
- Short-circuit current, I_{sc}
- Maximum power point, Pmp
- Module efficiency.
- Fill factor.
- Module temperature, °C
- Data and I-V curve corrected to standard conditions.
- Conforms to IEC 904-9.

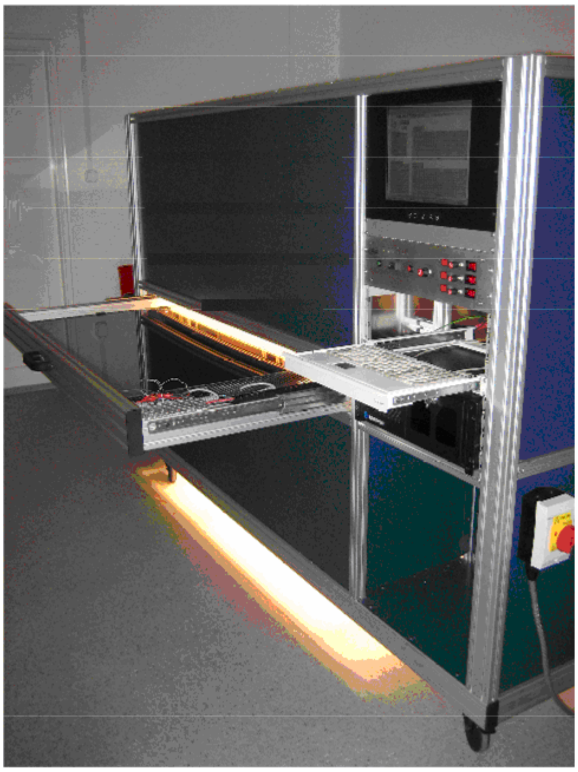


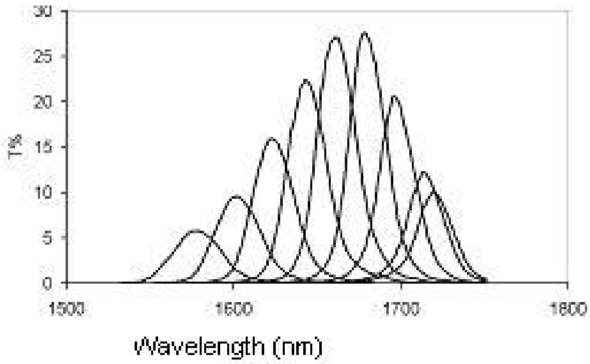
Fig. 3 *PVMT 11250 type continuous mode solar simulator.*

Research and development of custom wavelength IR sources and detectors

Vilmos RAKOVICS, János BALÁZS, Sándor PÜSPÖKI, István RÉTI, Magdolna VARGA FERENCNÉ, Katalin VÖRÖS VERESNÉ

The general aim of the project is the fabrication and development of IR LEDs emitting in the 1000-1700 nm wavelength range. The devices are used mainly in portable IR spectrometers. In 2006 two projects utilized these technique.

1.) The AQUANAL (NKFP) project, which aims the analyze of the phreatic water in Hungary. The related task is the detection of hydrocarbons in the water by IR absorption. Fig. 4 below shows the emission spectra of the light source developed for hydrocarbon analyzer. The spectrum of the light source can be modified by rotation of the interference filter. The wavelength



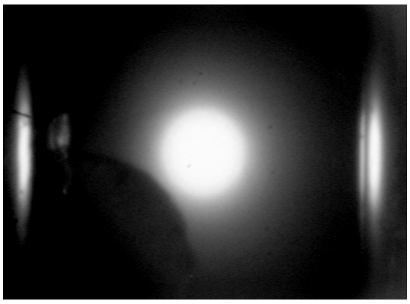


Fig. 4 *Spectra of the ligth source of hydrocarbon analyzer at various rotation angle of interference filter (left); and infrared image of the high brightness LED chip (right).*

of the ligth source can by adjusted according to the absorption bands of aliphatic, aromatic or clorinated hydrocarbons.

2.) The co-operative project with Ricola Ltd., Finland. High brigthness IR LEDs emitting at wavelengths of O-H and C-H absorption bands in near infrared region have been developed for selective spectroscopy.

Closed Space Electromagnetic Compatibility

(GVOP-3.1.1.-2004-05-0354/3.0)

Béla SZENTPÁLI, Tamás BERKÓ, Ferenc MOLNÁR, István RÉTI

The general aim of the project is the realization of electromagnetic compatibility (EMC) test in closed space. The standard EMC investigations in the radiated frequency range (usually above 1 MHz) are performed in open air avoiding the reflexions. In Hungary there are no such measuring plant. The measurement can be fulfilled also in unechoic chamber and/or in TEM cells. Naturally in these spaces more or less reflexions are always present. Therefore, the direct measurement of the radiating field is strongly recommended in the course of the EMC test.

The project is co-operative; the partner is the Bonn-Hungary Ltd. The task of the institute is the development of a field meter, which has only minimal disturbance on the field. The EMC measuring standard demands field uniformity below 6 dB. On the basis of an earlier project (AKP 96/2-604 2,3; 1997-98) a high frequency E-field probe was constructed from resistive transmission line. In the frequency range from 300 MHz to 1 GHz this structure has a maximum reflexion of about 0.4 dB. For comparison: the reflexion of the thinnest available coaxial cable (1.8 mm outer dia) of the same length is 20 dB.

Semiconductor Characterization Laboratory

Physics and Technology of Elemental, Alloy and Compound Semiconductor Nanocrystals

(EU FP6 project SEMINANO No. 505285, and Hungarian Scientific Research Fund under Grant No. T048696)

Zsolt J. HORVÁTH, Mária ÁDÁM, János BALÁZS, Péter BASA, László DOBOS, László DÓZSA, Tivadar LOHNER, György MOLNÁR, Péter PETRIK, Bálint PŐDÖR, Péter SZÖLLŐSI, Zsolt ZOLNAI

In this project Metal Nitride Oxide Semiconductor (MNOS) and Metal Nitride Semiconductor (MNS) structures with embedded Si nanocrystals have been produced by Low Pressure Chemical Vapour Deposition (LPCVD) method. The crystalline structure and the optical, electrical, and memory properties of these systems have been investigated using cross-sectional transmission electron microscopy (TEM), spectroscopic ellipsometry (SE), current-voltage (I-V), capacitance-voltage (C-V), memory window, memory hysteresis, and retention measurement methods.

Our best produced system shows a memory window of 9.7 V width for write/erase impulses of +/-15 V and 400 ms duration. Based on retention measurements, the extrapolated width of the memory window after 10 years operation is 2.0 V, 7.9 V, and 13.9 V for write/erase impulses of +/-1.5 V, +/-15 V, and +/-20 V, respectively.

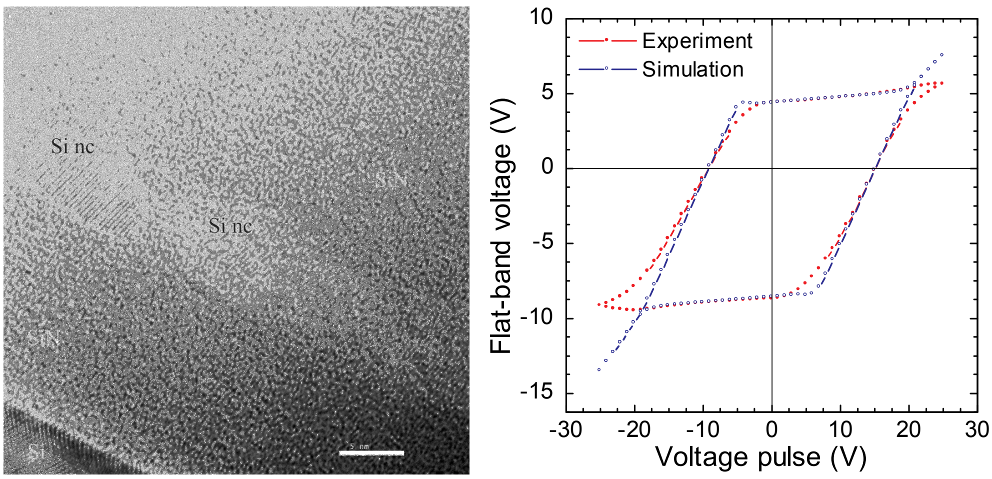


Fig. 1 *MNS structure containing Si nanocrystals separated by SiN_x bridges (left), and the calculated and measured memory hysteresis curves for the same system (right).*

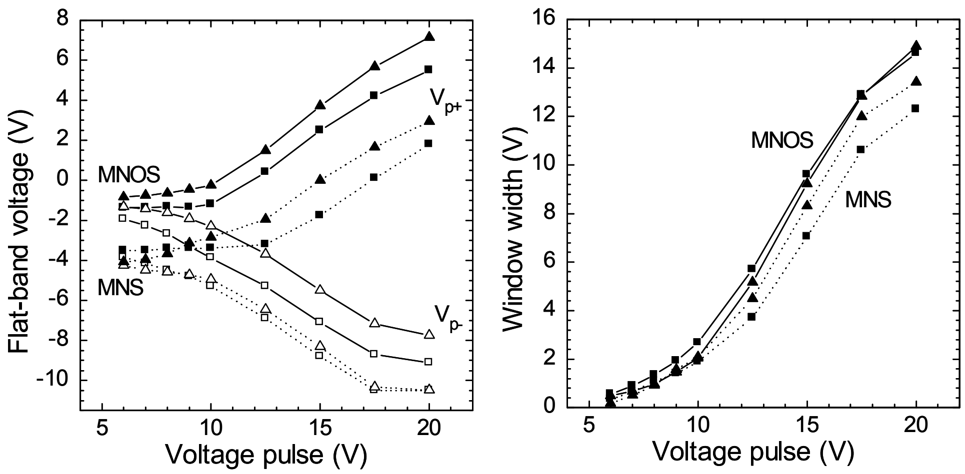


Fig. 2 *Memory features for MNS and MNOS structures with (triangle) and without (square) Si nanocrystals; solid line: with SiO_2 tunnel layer; dashed line: with SiN_x tunnel layer.*

Another research activity is the production of Ge nanocrystals (ncs) with evaporation technique on Si wafers covered by SiO_2 layers. The properties of the layers with nanocrystals were investigated using atomic force microscopy (AFM), scanning electron microscopy (SEM), and van der Pauw measurement techniques. The size of the nanocrystals vs. the sheet resistance of the layers showed a power function correlation. One set of samples was covered by SiO_2 overgrowth technique on top that was followed by transmission electron microscopy (TEM) measurements on the sandwiched SiO_2/Ge-nc/SiO_2 layer structures.

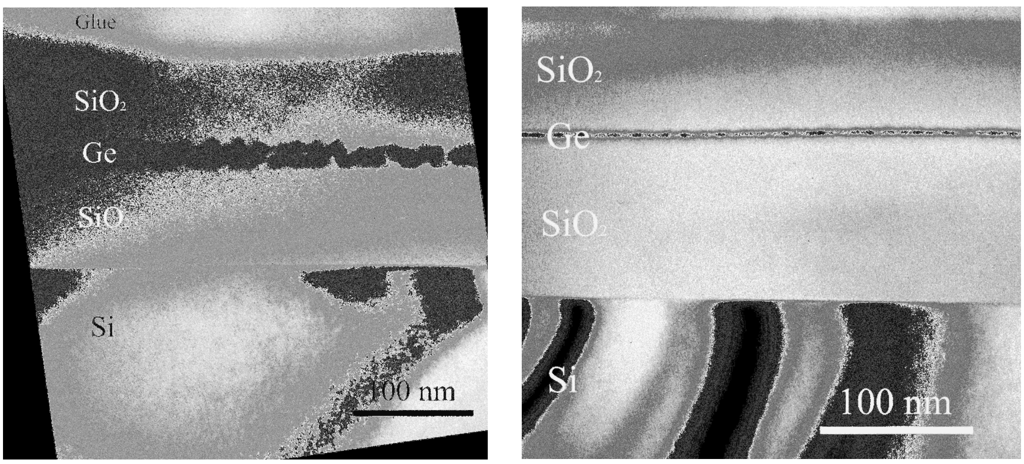


Fig. 3 *TEM micrographs of Ge nanocrystals embedded in SiO_2 layers.*

The oxidation kinetics of SiC and the formation of SiC nanocrystals at the SiO_2/Si interface

Hungarian-French academic exchange program

Gábor BATTISTIG, Anita PONGRÁCZ, Edit SZILÁGYI[a], Ian VICKRIDGE[b], Jean-Jacques GANEM[b], Isabelle TRIMAILLE[b]

[a]*Research Institute for Particle and Nuclear Physics, Budapest, Hungary*
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In this year our previous investigations for the understanding of the details of the oxidation process of SiC have been extended. The aim of this work is to understand the differences in the oxidation kinetics of the Si and C terminated polar faces of hexagonal SiC single crystals. With the investigation of SiO_2 layers grown at different oxygen partial pressures we have demonstrated that in this case the Deal-Grove kinetics governs the oxide growth process.

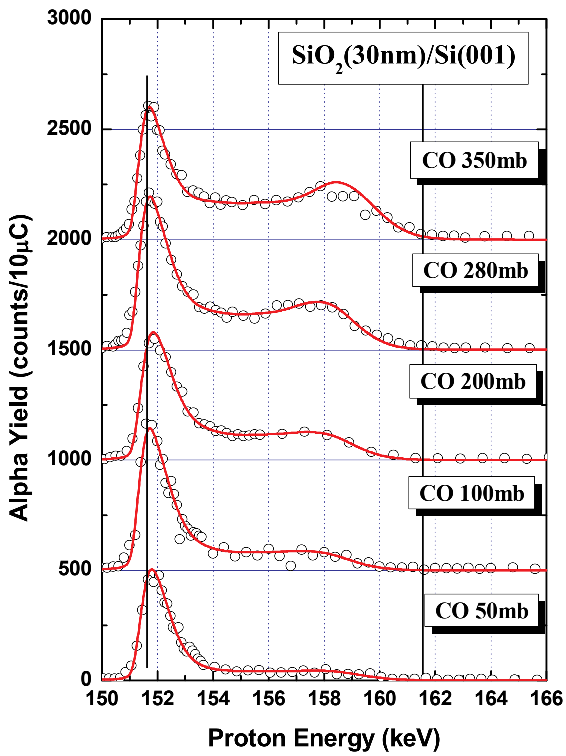

Fig. 4 *Proton beam NRA spectra from ^{18}O isotopes recorded on SiO_2(30 nm)/Si(001) layers after heat treatment at 1100°C for 1 hour in $^{13}C^{18}O$ with different pressures.*

In accordance with our previous results, the investigation of the properties of 3C-SiC nanocrystals (ncs) produced by simple reactive annealing of SiO_2/Si structure in CO ambient has been continued. For better understanding of the growth process of SiC ncs the annealing at 1100 °C was performed in $^{13}C^{18}O$ isotopic atmosphere. In this case the C and O content and depth distribution can be selectively observed in the grown layers. The Nuclear Reaction Analysis (NRA) spectra (see Fig. 4) show that in the grown layers the number of ^{18}O atoms is about 5-10 times higher than the number of ^{13}C atoms. Moreover, we concluded that most of the ^{18}O isotopes builds at the surface of the SiO_2 layer, and the $^{18}O/^{13}C$ ratio at the SiO_2/Si interface is close to 1/2. Further investigations are in plan to follow the atomic processes taking place during the CO treatment.

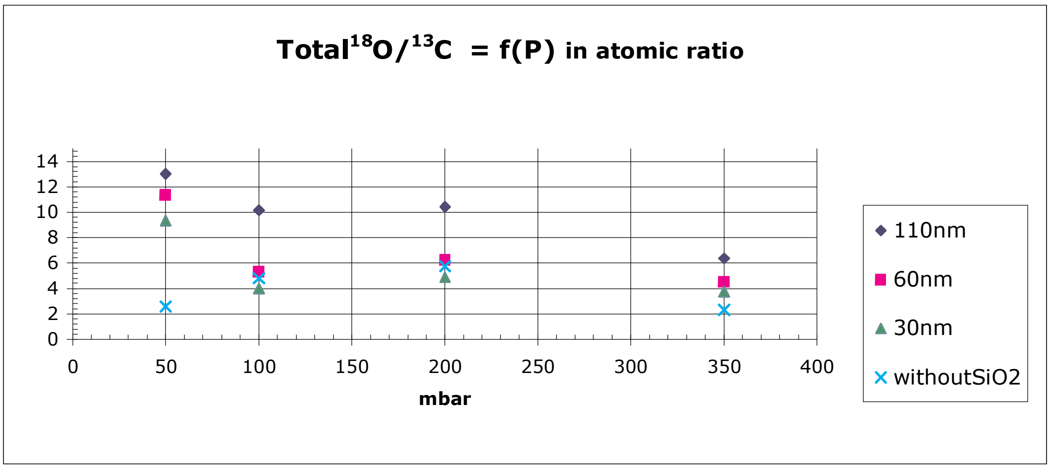

Fig. 5 *Total $^{18}O/^{13}C$ atomic ratio in $SiO_2/Si(001)$ layers with different SiO_2 thicknesses after heat treatment at 1100°C for 1 hour in $^{13}C^{18}O$ with different pressures.*

We have also investigated the effect of the thickness of the covering SiO_2 layer on the O/C ratio after high temperature exposure of the SiO_2/Si structure in CO at various pressures (Fig. 5). The results have also shown that $^{18}O/^{16}O$ exchange dominates at the surface region of the SiO_2 film more or less independently with the thickness of the SiO_2 layer.

Ion implantation and annealing of SiC single crystals

Gábor BATTISTIG, Nguyen Quoc KHÁNH, Péter PETRIK, Tivadar LOHNER, László DOBOS, Béla PÉCZ, Lajos TÓTH, J. GARCÍA LÓPEZ, Y. MORILLA, András STER, Matthias POSSELT, Endre KÓTAI, József GYULAI

It is an accepted idea that the devices produced by doping SiC, with donors or acceptors, have a great prospective for an extensive range of microelectronics applications. However, the local doping can only be performed by ion implantation due to the very low diffusivity of the dopants in SiC even at high temperature. The disorder induced by the implantation process depends not only on the energy and fluence of the implanted species but also on the direction of the bombarding ions with respect to the crystallographic axes. If the implantation is performed along low index crystallographic directions, ion channeling occurs resulting in deeper dopant penetration and less defect generation. Accordingly, channeling implantation might be a promising way to reduce the irradiation-induced disorder.

Therefore, we investigated the influence of crystallographic orientation and ion fluence on the shape of damage distributions induced by 500 keV N^+ implantation at 300 K into 6*H*-SiC. The irradiation was performed at different tilt angles between 0° and 4° with respect to the <0001> axis in order to consider the whole range of beam alignment from

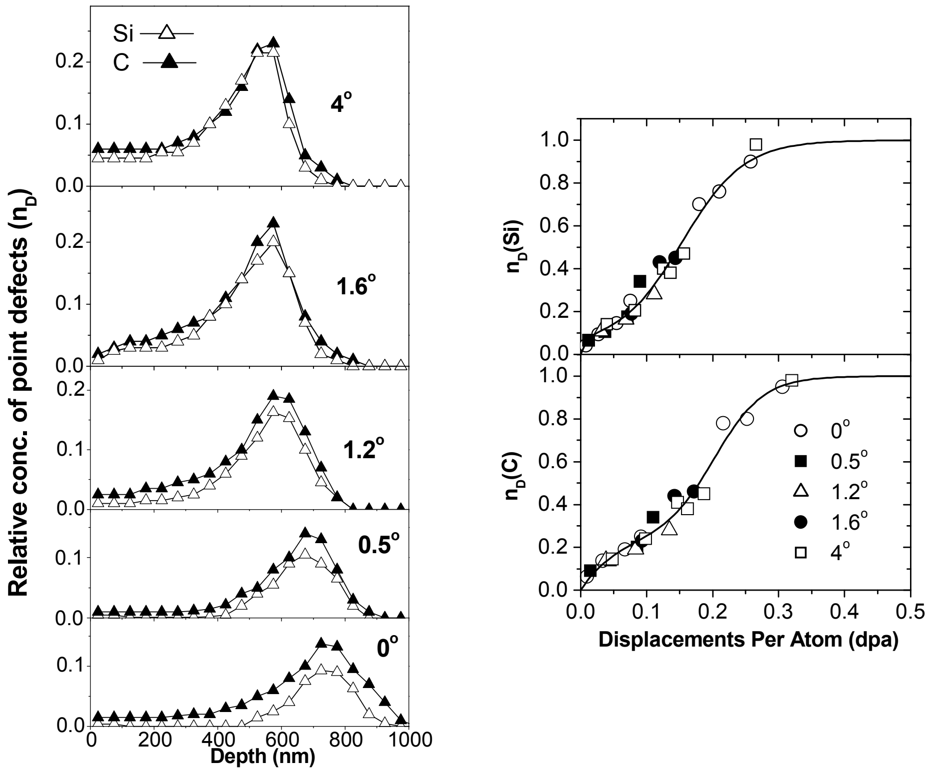

Fig. 6 *Left: Relative concentration of point defects n_D on the Si and C sublattices of 6H-SiC vs. depth for 500 keV N^+ implantation to a fluence of 5×10^{14} cm^{-2}.*
Right: n_D(Si) and n_D(C) vs. displacements per atom at the damage peak for 500 keV N^+ implantation to different fluences and different tilt angles with respect to the <0001> axis. Symbols: results of BS/C analysis; Solid lines: best fits of the direct-impact, defect-stimulated amorphization model.

channeling to random conditions. A special analytical method, 3.55 MeV $^4He^+$ ion backscattering/channeling technique (BS/C), was employed to measure the disorder accumulation simultaneously in the Si and C sublattices of SiC. For correct energy to depth conversion in the BS/C spectra, the average electronic energy loss per analyzing He ion (S_e) for the <0001> axis was determined. We found a channeling to random ratio of 0.8 for S_e.

It was found that the tilt angle of the implantation has strong influence on the shape of the disorder profiles. Significantly lower disorder was found for <0001> channeling than for random irradiation. RBX computer simulation of the measured BS/C spectra showed the presence of a simple point defect structure in weakly damaged samples and suggested the formation of a complex disorder state with extended defects and strain for higher disorder levels. The damage buildup mechanism was interpreted with the direct-impact, defect-stimulated amorphization model which describes the composition of structural disorder versus the ion fluence and the implantation tilt angle (For details see: Journal of Applied Physics 101 023502 (2007)).

In another experiment, 4*H*-SiC single crystalline substrates were implanted at 300 K with 150 keV Al^+ ions and post-annealed at 1100 °C in N_2 for 1 h in order to analyze their structural recovery. The disorder induced in both sublattices by the Al^{+} ions was studied using BS/C technique. The results were compared with the optical properties of the samples measured by spectroscopic ellipsometry (SE). Cross-sectional transmission and high resolution electron microscopy studies, together with BS/C and SE results, confirmed that during the postimplantation annealing of a highly damaged SiC crystal the short distance order can be recovered, while the long distance disorder remains. We also presented the possibility to have grains of different polytypes oriented faraway from the original direction [20].

The effect of pulsed laser annealing on implantation-amorphized Si and SiC thin layers was investigated using Nd:YAG laser with 5 ns pulse length at different emission wavelengths of λ= 1064 nm, 532 nm, and 355 nm. Multiple energy Ar^{+} implantation has been applied to get uniformly damaged layers on the top of Si and SiC single crystals. The effect of the laser wavelength and the thickness of the amorphized layer on the recrystallization, defect annealing, and the diffusion of the implanted Ar^{+} ions was investigated by BS/C technique. We found that pulsed laser annealing at λ= 532 nm for SiC and at λ= 1064 nm for Si has qualitatively similar effect on defect removal and Ar diffusion. The top layer seems to be melted and a fraction of Ar atoms leave the surface, whereas partial defect annealing occurs in the whole damaged layer. Decreasing the thickness of the amorphized layer or applying a laser wavelength of 355 nm drastical changes cannot be observed after pulsed laser annealing of amorphized SiC layers.

Investigation of silicon/silicide and InGaAs/GaAs quantum structures

Hungarian-Italian, Hungarian-Czech, and Hungarian-Russian Academy exchange program, Hungarian-Greek bilateral intergovernmental cooperation

L. Dózsa, L. Tóth, A. A. Koós, G. Molnár, N. Q. Khánh, N. G. Galkin, J. Oswald, P. Hubik, and C. A. Dimitriadis

The reduction of the size of devices necessitates the development of new technologies. Nanoscale structures show several new phenomena, and offer possibility to produce new devices based on quantum size effects. Their application is promising in optical, memory, thermoelectric etc., applications. The quantum structure of a given material is realized in a matrix of another material which implies a practically infinite combination of the components, which can be applied only in large groups. The results described hereinafter were achieved in the frame of several international cooperations. InAs quantum dot structures produced by MBE are investigated at the Italian Research Institute in Parma and at the Thessaloniki University in Greece. InGaAs/GaAs quantum well (QW) structures are investigated at the Institute of Physics of Prague in Czech Republic. We are also in contact with the Institute for Automation and Control Processes in Vladivostok, Russia. The main task of all these cooperation is the investigation and development of quantum size devices on silicon/silicide and GaAs/InAs systems.

The investigated samples of different materials are produced in the cooperating laboratories. The InGaAs/GaAs QW structures are prepared in Prague by low pressure metal-organic vapour phase epitaxy. The β-$FeSi_2$ quantum dots (QD) on silicon are prepared by solid phase epitaxy and reactive deposition epitaxy at the MFA in Budapest, Hungary, while the β-$FeSi_2$ QD multilayers covered by silicon epitaxial layers and the $CrSi_2$ quantum dot structures were prepared in Vladivostok, Russia.

The structures were investigated by the following experimental techniques which are available at the cooperating institutes: photoluminescence (PL), transmission electron microscopy (TEM), high resolution TEM (HRTEM), far infrared (FIR) measurements, atomic force microscopy (AFM), Rutherford backscattering spectrometry (RBS), scanning electron microscopy (SEM), the measurement of current-voltage (I-V) and capacitance–voltage (C-V) characteristics, deep level transient spectroscopy (DLTS), low frequency noise (LFN) measurements, ultraviolet photoelectron spectroscopy (UPS), and optical reflectance spectroscopy (ORS). The apparently scattered technical background shows that in the research of nanostructures large investments are needed and, also, the interpretation of the results necessitates the cooperation of several experts of different measurement techniques.

InGaAs quantum wells in GaAs matrix

QWs with the size of 5,8,12, and 16 nm were grown in a series of samples on a 0.7 μm thick GaAs buffer layer. All the layers were doped to 3 $10^{16}/cm^3$. The thick buffer layer and the doping level was selected for investigation of electrical transport properties in parallel and perpendicular to the QW plane. For reference a thin structure was grown containing three QWs of 9, 5, and 3 nm width with 50 nm width of undoped buffer, spacer, and cap layers. The latter structure has shown atomically flat surface, the RMS surface roughness measured by AFM being below 1 nm. The series of QW samples on doped, thick substrate exhibited rough surface in AFM with typical RMS roughness of 10 nm. The morphology of the thick buffer doped samples was similar, with the periodicity of the surface being around 4 mm. It indicates there is a unique mechanism behind the irregular growth. The AFM images of the thin undoped and the thick doped buffer samples are compared in Fig. 7. The PL peak position in both samples is found at the theoretically expected positions. The PL spectra of the flat QW samples exhibited narrow PL peak compared to the rough surface samples, as it is illustrated in Fig. 8. In thick samples the C-V and I-V measurements show that the QWs are at the theoretically expected position and show density of states in the QW. DLTS does not show the presence of point defects in the GaAs layer or at the QWs. The emission of the 2D electrons from the QW is not detected by DLTS. We assume it is a results of combination of lateral and perpendicular conductivity which can empty the 2D electron states at high electric field or degraded singular regions of the QW barrier. HRTEM shows defect-free strained InGaAs QW lattice matched to the GaAs lattice, as it is shown in Fig. 9.

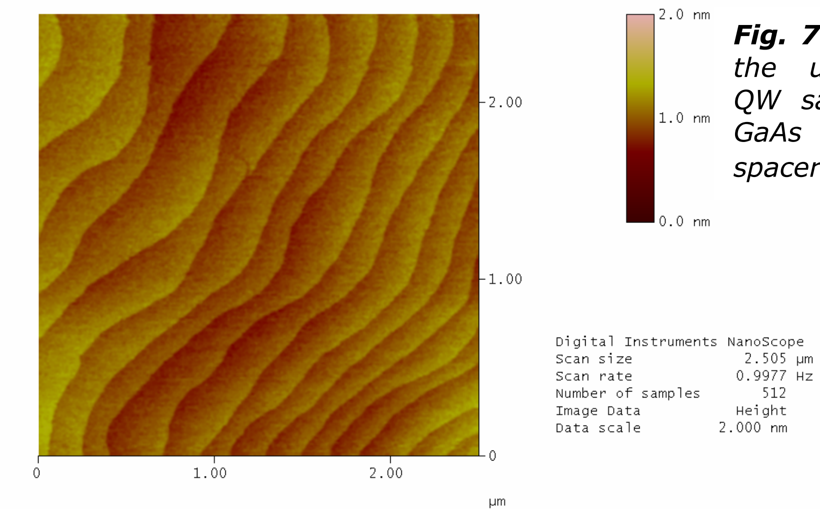

Fig. 7a *AFM image of the undoped InGaAs QW sample grown on GaAs with thin buffer, spacer and cap layers.*

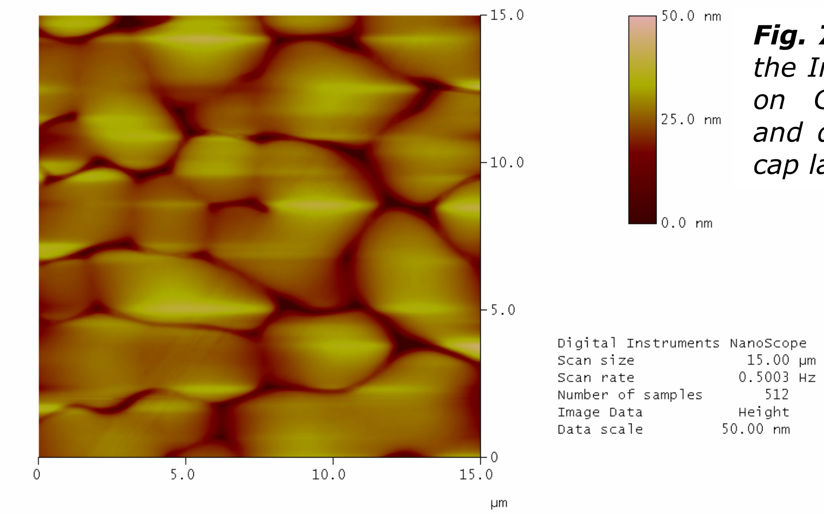

Fig. 7b *AFM image of the InGaAs QW grown on GaAs with thick and doped buffer and cap layer.*

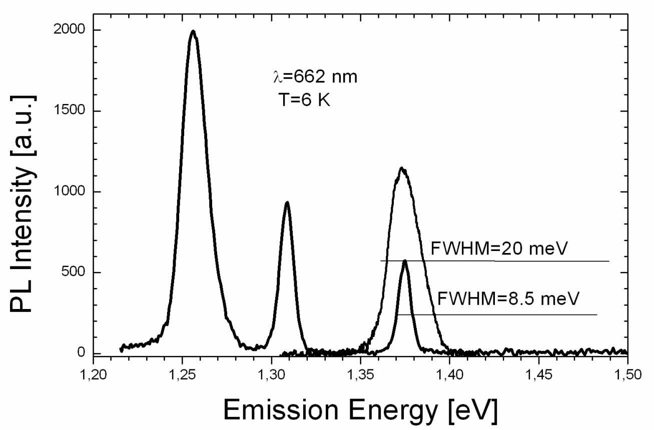

Fig. 8 *The PL spectra of the three InGaAs QW sample on undoped thin buffer, spacer, abd cap layer sample, and from the single QW sample with thick doped buffer and cap layer. The PL peak from the thick buffer sample is broad.*

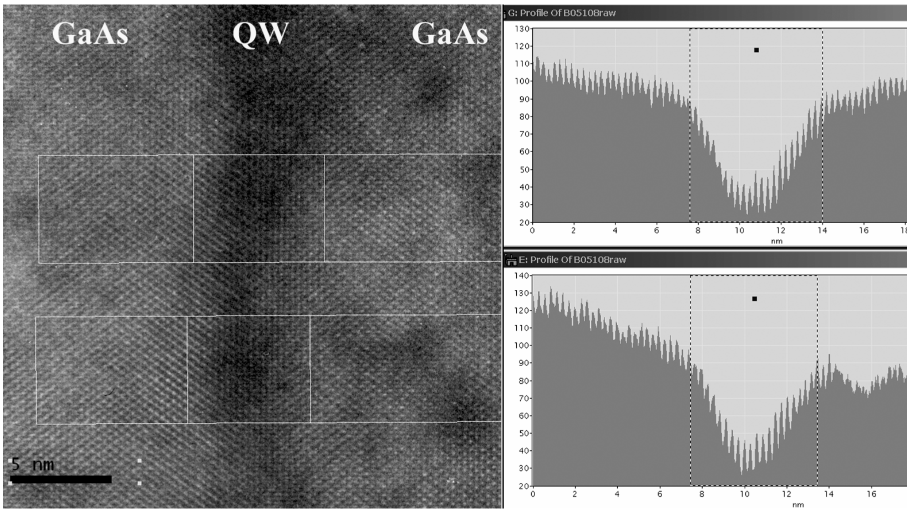

Fig. 9 *To the left: HRTEM image of the QW region. Both the QW and the GaAs host matrix are defect free. To the right: the profile shows the averaged intensities in the regions marked by white rectangular frames in the image. The analysis shows that the InGaAs QW is strained and lattice matched to the GaAs layer.*

β-FeSi₂ quantum dots on silicon

TEM and FIR measurements on QD structures grown at different temperatures and from different layer thicknesses have shown that from solid phase epitaxy the β-$FeSi_2$ phase is grown from several nm Fe deposition, while in RDE deposition at the same annealing temperature (600 ^{o}C) the resulted iron-disilicide phase is mixed mostly from β and γ phases. For the effective RDE growth of the β-$FeSi_2$ phase, the silicon substrate temperature has to be reduced to approximately 500 ^{o}C, and the deposited Fe layer thickness has to reduced to about 0.1 nm. TEM and FIR measurements show that with decreasing the Fe layer thickness the fraction of the β-$FeSi_2$ phase is increased. The optimal growth parameters are in agreement with those obtained in Vladivostok.

The major motivation of the research of the β-$FeSi_2$ phase is its expected PL emission at 1.5 mm wavelength. However, it seems that the point defects created by the Fe in silicon drastically reduce the luminescence efficiency. There is a large point defect concentration in all the Fe treated silicon structures. The presence of defects was detected by DLTS and LFN measurements. The Fe compensates both the n and p dopants in silicon in an about 1 μm thick region. Up to date there is no any method known to remove these defects, which may limit the application of $FeSi_2$ layer to photodetector or solar cell applications. However, the quantum size may offer some new application due to the wide variety of the Fe-Si reaction.

$CrSi_2$ nanocrystallites grown in silicon matrix

Semiconducting $CrSi_2$ (E_G=0.35 eV) nanocrystallites were grown by reactive deposition epitaxy at 500 °C on n-type 7.5 Ωcm (111) silicon substrate. This structure was covered by a 100 nm thick silicon layer grown by MBE at 750 °C resulting in $CrSi_2$ nanocrystallites embedded in silicon. The growth was carried out in an ultra high vacuum chamber with a base pressure of 2×10^{-10} Torr. A series of this structure was grown with deposited Cr thickness in the 0.1–1.5 nm range.

The crystalline structure, morphology and optical properties were investigated by TEM and AFM. The presence of $CrSi_2$ phase in the Si matrix has been justified by UPS, ORS, and TEM measurements. The point defects were investigated by DLTS and RBS. The crystal structure of the nanocrystallites has been identified by high resolution TEM as hexagonal $CrSi_2$ matched to the silicon lattice. Energy filtered TEM shows that most of the Cr atoms is localized in the nanocrystals. RBS (Fig. 10) measures $4x10^{20}/cm^3$ concentration of Cr in the silicon cap layer. Most of the 0.1 nm deposited Cr diffuses to the surface during the silicon cap epitaxy, while from 1.5 nm Cr most of the Cr remains near the deposition interface.

Electrical characteristics and DLTS show that the concentration of electrically active Cr is small as compared to the values measured by RBS. DLTS spectra show the presence of two point defect centers: (i) the Cr-B pair in the epitaxial silicon layer with a level at E_V+0.23 eV and (ii) the Cr level at a position of E_C-0.27 eV. At high Cr content the (ii) center dominates the DLTS spectra.

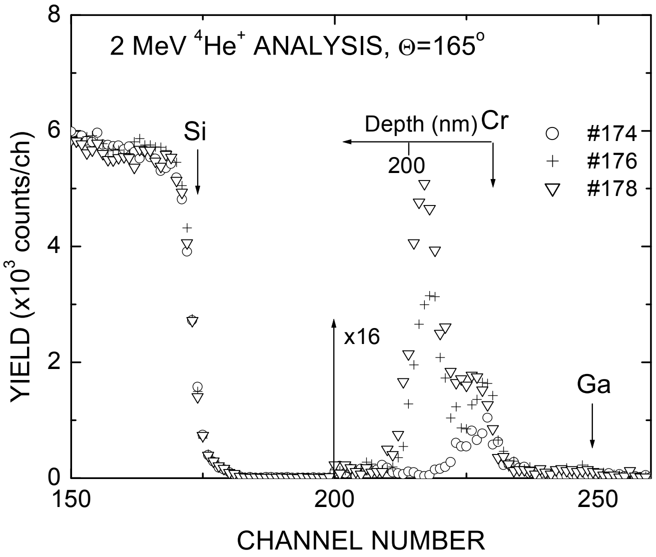

Fig. 10 *RBS spectra of the RDE deposited Cr samples. The labels #174, #176, and #178, are corresponding to Cr thicknesses of 0.1 nm, 0.6 nm, and 1.5 nm, respectively.*

Photonics Department

Laboratory for Nondestructive Analysis	**Semiconductor Photonics Laboratory**	**Bioengineering Laboratory**
Head: Tivadar LOHNER, Ph.D. **Staff:** Csaba DARÓCZI, dr. univ. Imre EÖRDÖGH, M.SC. Miklós FRIED, D.Sc. Antal GASPARICS, Ph.D. György JUHÁSZ, dr. univ. István E. LUKÁCS, Ph.D. Péter PETRIK, Ph.D. Olivér POLGÁR, Ph.D. Ferenc RIESZ, Ph.D. Károly SZÁSZ, M.SC. Erika TUNYOGI, M.SC. Gábor VÉRTESY, D.SC. **PhD Student (Advisor):** Csaba MAJOR (Miklós Fried)	**Head:** Miklós SERÉNYI, C.Sc. **Staff:** János BALÁZS, M.Sc. (part time) András HÁMORI, dr. univ. György KÁDÁR, D.SC. Sándor KURUNCZI, Ph.D. János MAKAI, Ph.D. (part time) Mária Rózsa JANKÓNÉ, technician Erzsébet MÉSZÁROS, technician Miklós RÁCZ, dr. univ. (part time) Péter TÖRÖK, D.Sc. (on leave) Péter VARGA, Prof. Emeritus, D.Sc. Ferenc VONDERVISZT, Prof., D.SC. (part time) **PhD Student (Advisor):** Norbert NAGY (István BÁRSONY & András HÁMORI)	**Head:** György KOZMANN, D.Sc. **Staff:** Krisztina SZAKOLCZAI, M.SC. Andrea CSALÓTZKYNÉ BOLGÁR, engineer **PhD Student (Advisor):** Kristóf HARASZTI (György KOZMANN)

Laboratory for Nondestructive Analysis

Electromagnetic reading system of laser marked logistic bar codes

(GVOP-3.1.1- 2004 – 05 -0452/3.0)

Gábor VÉRTESY, Antal GASPARICS

For identification of metallic components laser scribed marker lines can be used as logistic codes, created by CO_2 laser irradiation in the surface layer. The markers have been investigated with very good signal/noise ratio by the Fluxset type eddy current probe [177]. For optimization of marker density methods of computational electromagnetism have been used for the development of the electromagnetic reading out system [57,177]. The markers have been reconstructed from the signal of the eddy current probe.

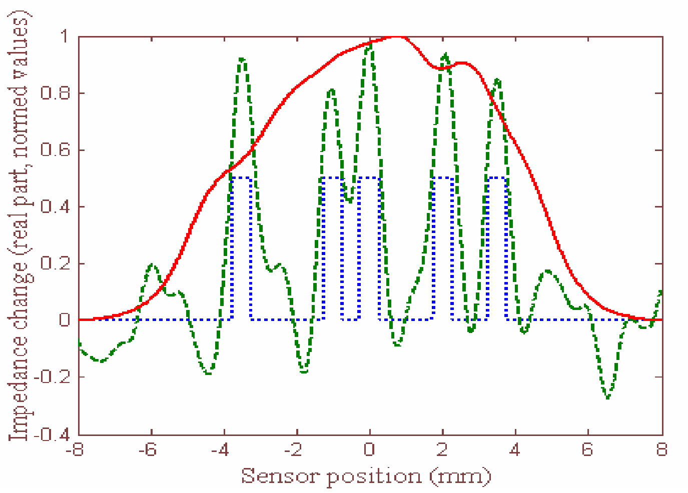

Fig. 1 *Example of deconvolution of 5 marker lines. (Dotted line: position of the marker lines. Solid line: measured signal of the 5 marker lines. Dashed line: signal after deconvolution)*

A computational model of the reading out process has been developed by which both the code specification and the probe can be optimized. Based on this evidence a deconvolution algorithm has been proposed for the estimation of marker line positions. The proposed method is successfully applied for the deconvolution of overlapping signal of five marker lines. As a result it is proved that high density barcodes can be read out by the described method even if a simple device is applied for the measurements.

Magnetic investigation of power plants' structural materials degradation

(Hungarian Scientific Research Fund under Grant No. K62466)

Gábor VÉRTESY

A new, nondestructive magnetic measurement has been developed [176,181,182], which is based on systematic measurements of minor magnetic hysteresis loops. This technique is able to serve as a powerful tool

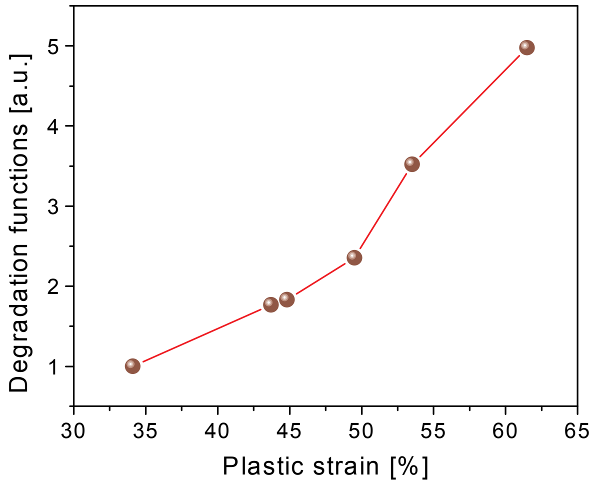

***Fig. 2** Degradation functions of cold rolled austenitic steels, obtained by Magnetic Adaptive testing, as a function of plastic strain.*

for comparative measurements, and for detection of changes, which occur in structure of the inspected samples during their lifetime or during a period of their heavy-duty service.

It has shown that the outcome of this method, Magnetic Adaptive Testing, is significantly more helpful than that of the traditional major loop studies. It is highly suitable for very sensitive nondestructive characterization of structural changes in such materials. Another advantageous and independent outcome of the tested method is the confirmation, that without magnetic saturation of the samples, measuring a series of minor loops and performing the Magnetic Adaptive Testing method on the obtained data-pool, reliable and very sensitive parameters can be determined. Moreover, the relative measurement can be done with a ferromagnetic yoke attached to the sample, and the yoke does not even have to be large and very special.

The capability of the method has been illustrated on plastically deformed austenitic steel samples [179,180]. (Plastic deformation generates ferromagnetic phase in the originally paramagnetic material.)

Quantitative Makyoh topography

(Hungarian Scientific Research Fund under Grant No. T 037711)

Ferenc RIESZ, János P. MAKAI, István E. LUKÁCS

The construction of a novel Makyoh topography setup using a parabolic mirror as an imaging element has been completed [98]. The setup is capable of studying the qualitative surface morphology and quantitative curvature/flatness of semiconductor wafers up to about 5 inch diameter (the latter uses a projected grid). The optical construction allows high dynamic range. The equipment is routinely used for the assessment of various semiconductor processing steps in our laboratory as well as in several collaboration projects.The sensitivity of qualitative Makyoh topography was studied theoretically, and expressions for the surface detection height sensitivity were given [144].

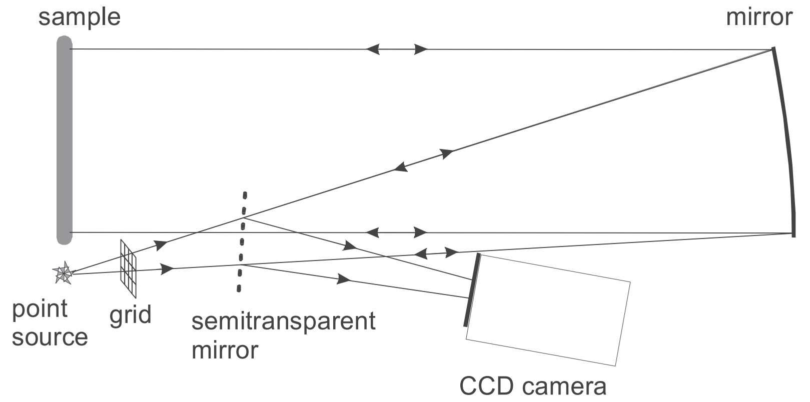

Fig. 3 *Scheme of the mirror-based Makyoh-topography setup.*

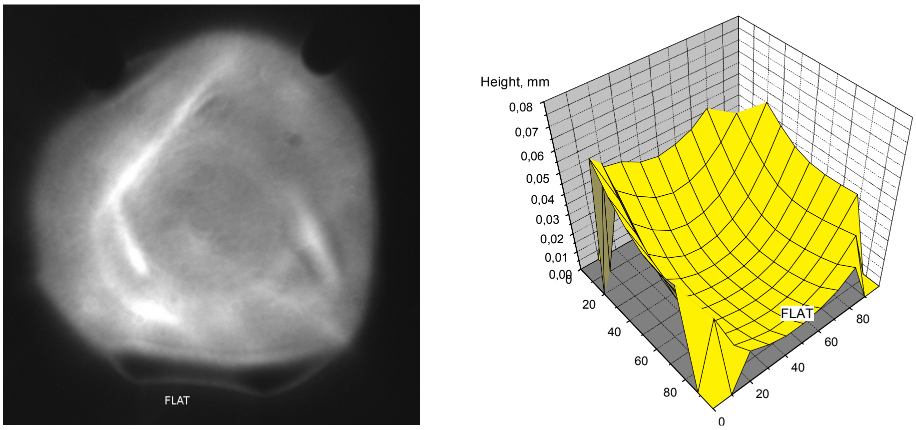

Fig. 4 *Makyoh topography image (left) showing the qualitative morphology and the large-scale surface topography (right) of the same wafer as determined by grid-projection Makyoh topography.*

It was also shown within the framework of this project that if the screen-to-sample distance is much smaller than the local curvature radii of the surface, the expression of the image intensity does not contain the Gaussian curvature of the surface [146].

Development of optical models for ellipsometric study of multicomponent materials

(Hungarian Scientific Research Fund under Grant No. T 047011)

Miklós FRIED, Tivadar LOHNER, Péter PETRIK, Olivér POLGÁR, Norbert NAGY

Optical and x-ray characterization of ferroelectric Strontium-Bismuth-Tantalate (SBT) thin films was carried out [41].
The validity of various effective medium approximations (EMAs) (Bruggeman, Maxwell-Garnett) was studied for nanostructured systems, where the scale of inhomogeneities is comparable to the wavelength. Langmuir-Blodgett (LB) layers of Stöber silica nanospheres of diameters between 40 and 129 nm are excellent model structures for the experimental verification of the validity of the EMA methods in spectroscopic ellipsometry (SE) evaluation. Nanostructured mono- and multilayered films were

investigated by SE. The effective refractive index and the film thickness were determined from the results of multiparameter fitting of SE spectra in the 300-759 nm wavelength region. The distribution of the effective refractive index in the particulate films was calculated assuming an ideal close-packed arrangement of particles. The average deviation from such a structure was deduced from the corrected model by introducing a "fill factor" [105].

The evaluation strategies for multi-layer, multi-material ellipsometric measurements has been developed [132].

Péter Petrik could spend half a year as a grantee of the "Hungarian-American Enterprise Scolarship Fund" (HAESF) at the research group headed by Professor Robert Collins at Toledo Univesity (Ohio, USA) working in the field of the optical characterization of deposited and ion implanted CdTe and CdS thin films. An auxiliary support (Hungarian Scientific Research Fund under Grant No. 64195) made possible for Miklós Fried to join to this research.

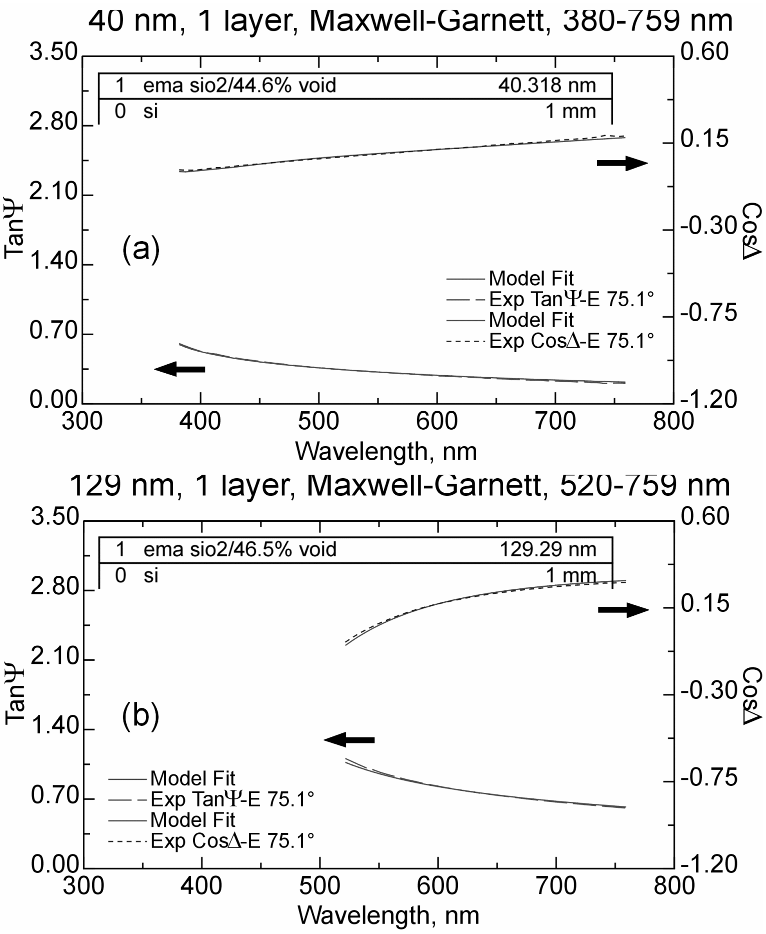

Fig. 5 *Experimental and generated SE spectra of the monolayer films composed of 40 (a) and 129 nm (b) diameter particles using the Maxwell-Garnett EMA in the 380-759 and 520-759 nm wavelength region, respectively.*

Ellipsometric modelling of nanograin structures and thin films for biological and (opto)electronical applications

(Hungarian Scientific Research Fund under Grant No. K61725)

Péter PETRIK, Nguyen Quoc KHÁNH, Sándor KURUNCZI, Olivér POLGÁR

The dielectric function of disorder in high-fluence helium-implanted silicon was deduced from the evaluation of spectroellipsometric measurements [128]. Optical models were developed for the ellipsometric characterization of nanocrystals in porous silicon [129, 131] and carbon nitride layers prepared by inverse pulsed laser deposition [130].

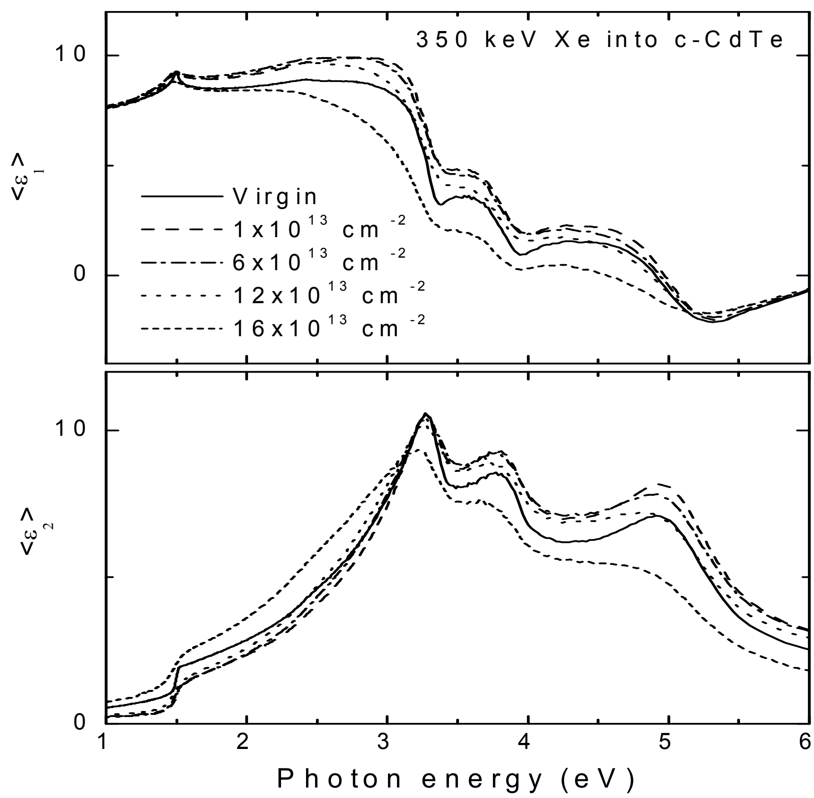

Fig. 6 *Pseudo-dielectric function of c-CdTe implanted by 350 keV Xe.*

Wide-angle ellipsometry

(GVOP –3.1.1-2004-05-0435/3.0 AKF project [2005-2007])

Miklós FRIED, György JUHÁSZ, Csaba MAJOR, Zoltán Gy.HORVÁTH*
*Research Institute for Solid State Physics and Optics, Budapest, Hungary

The „point source – pin hole camera" type wide-angle ellipsometer setup was completed and tested. With the help of a DAAD-MÖB support the adaption of the equipment to a vacuum system was implemented in the Fraunhofer Institute of Integrated Systems and Device Technology (IISB) in Erlangen, Germany.

European Integrated Activity of Excellence and Networking for Nano and Micro-Electronics Analysis

(EU I3, ANNA Projekt No. 026134 (2007-10))

Péter PETRIK

The ANNA project aims to offer European universities, research institutes, large companies and small and medium-sized enterprises a joint laboratory that addresses threats to the growth of their nanotechnology and microelectronics sector. The companies and researchers involved will benefit from the efforts to solve the challenges they face when using new technology. The twelve partners started the project in December 2006. (http://fcs.itc.it/anna/index.html)

Development and application of special image processing methods

Head: Imre EÖRDÖGH

Special image processing methods were developed and applied for solving medical, dosimetric [122] and fabrication related technological tasks. The prototype of the **INANALRG** morphometric medical equipment has been elaborated together with the diagnostic software.

Semiconductor Photonics Laboratory

Opto-electronic devices based on the protein Bacteriorhodopsin

(Supprted by the NATO project number of SfP964262)

András HÁMORI, Norbert NAGY, Miklós SERÉNYI

Different waveguides [152] including in-, and outcoupling grating, and Mach-Zender interferometer were prepared on Suprasil substrate by Ta_2O_5 thin film. Mach-Zender interferometer fabricated by newly developed RIB technology is suitable for coupling to monomode optical fiber.

AQUANAL

(NKFP 3A/079/2004)

István BÁRSONY, András HÁMORI, Sándor KURUNCZI, Norbert NAGY, Miklós SERÉNYI

The aim of the project is the analysis of the natural water basis using micro- and nanosensors. A simple device was developed for the monitoring of the oil film on the surface of the water. Detectors built-in a conical form optical head measure the deviation of the total reflected light and an electronic circuit signals the presence of the pollution. Characterization of Salmonella FliS flagellar chaperone interaction with flagellin was performed. Flagellin film was prepared on the surface of waveguide for optical detection of the heavy ionic pollution [48, 104, 173].

Electromagnetic waves in artificial periodical structures

(Hungarian Scientific Research Fund under Grant No. T046696)

András HÁMORI, György KÁDÁR, Norbert NAGY

Numerical model for the wave spreading in two dimensional photonic crystals was developed [159, 160]. Large area self-assembled masking using Langmuir-Blodgett technique was applied to prepare periodical structures on semiconductor surface [105, 106].

Bioengineering Laboratory

Developing high-resolution brain electro-mapping (BEM)

(NKFP 2/004/2004)

György KOZMANN, Krisztina SZAKOLCZAI, Kristóf HARASZTI

In the frame of our Brain Electro-Mapping (BEM) project we have completed the data acquisition unit and data processing software. Currently we are able to collect 128-channel data in our self defined eeg format, furthermore we are able to convert int24 files into int32 format. A linear baseline correction algorithm and an adaptive 50 Hz filter has been integrated in the processing software. For high-precision evoked potential measurements auxiliary units for precisious finger-tapping detection and EOG module for eye movement or blinking artifact detection have been developed and integrated.

Because power line interference could cause significant artifacts in the recorded signals, clinical data acquisition is carried out in the shielded room of our partner institute (National Institute for Psychiatry and Neurology).
Measured or computed signals are visualized by color-coded potential distribution maps, RMS maps, Laplacian maps, frequency maps, etc. on the scalp or on the brain surface (Fig. 1).

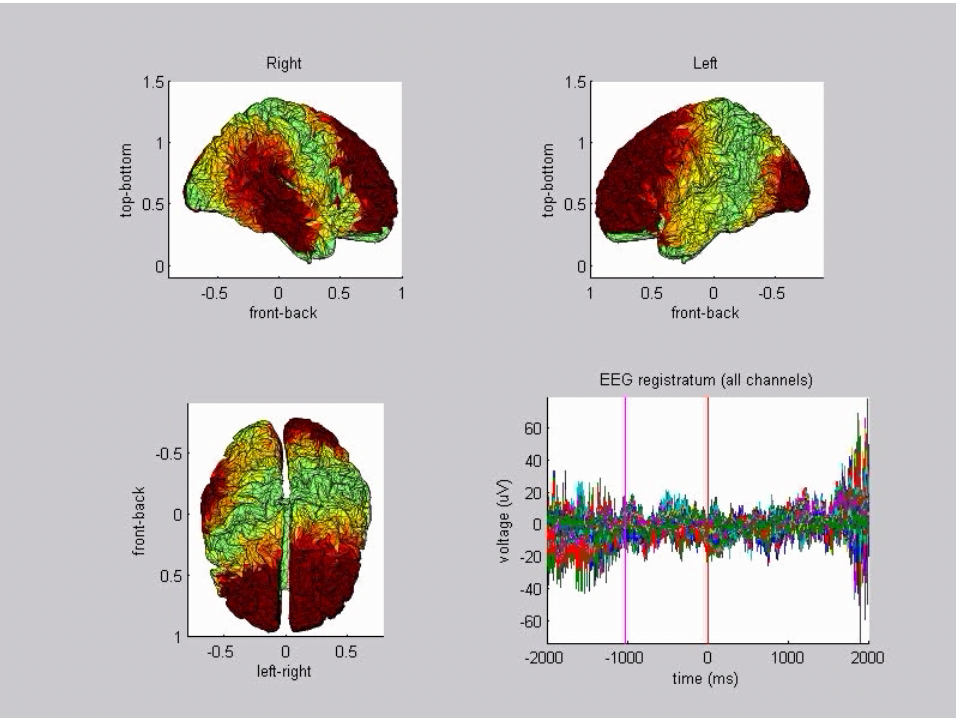

Fig. 1 *Example on a color-coded momentaneous cortical current-distribution map*

Intelligent physiological telemonitoring system

(GVOP AKF 0196/2004)

György KOZMANN, Krisztina SZAKOLCZAI, Kristóf HARASZTI, Andrea CSALÓTZKY BOLGÁR

The aim of the project is to develop an intelligent measuring and supervising system for monitoring and transmitting of physical, circulatory and emotional status, work load and environmental load. The major components of the system comprise robust wearable sensors and signal conditioners with bluetooth or cable connection to the local portable data acquisition module. Data processing will be carried out in two steps, locally and in a centralized surveillance system. Data transmission will use radio frequency carrier. The location of the patient is also monitored with GPS.

Sensors already have been developed to measure ECG, O_2 saturation, pulse, skin resistance, skin temperature and also physical activity. All of those have been integrated to a special dress, capable of holding all the sensors without significantly influencing the everyday life of the user. Prototypes of data acquisition, amplifier, pre-processor and transmitter are also under test phase together with central database and client-server data visualization programs.

We assume that more details can be gained from the status of the user by analyzing the set of parallel measurement values then making decisions on a single parameter. Therefore complex data evaluation method will be developed based on medical knowledge and a mathematical model. Decision support system will be personalized and we will use classification thresholds gained from the patient’s reference measurement.

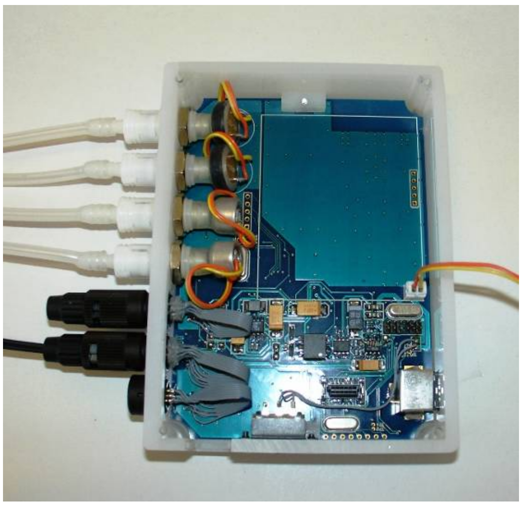

Fig. 2 *Data acquisition module*

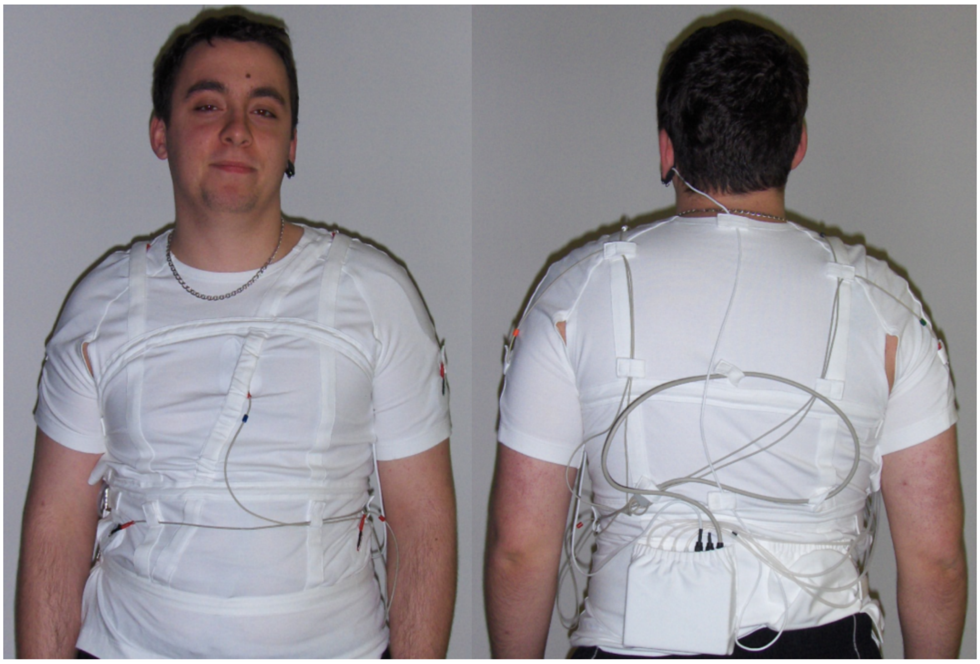

Fig. 3 *Prototype of the integrated sensor carrier clothes (front and back)*

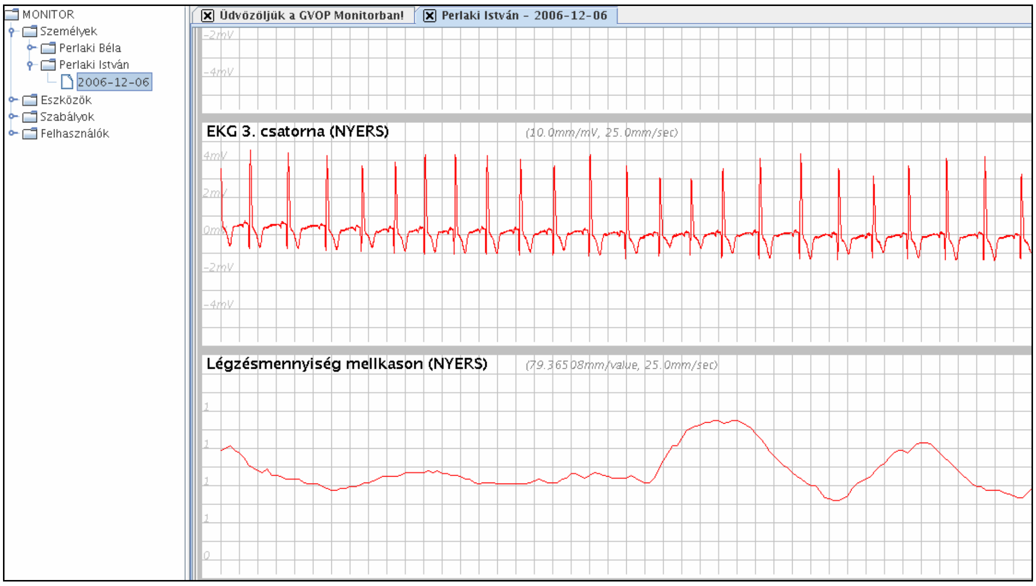

Fig. 4 *Screenshot of the visualization program (one of the unprocessed ECG channels above and one of the respiratory curves below)*

Assessment of arrhythmia vulnerability

György KOZMANN, Kristóf HARASZTI

The recognition of the substrate of malignant arrhythmias needs a detailed spatio-temporal noninvasive characterization of dynamic changes in beat-to-beat cardiac repolarization. In our approach body surface mapping, BSPM, was used to access the whole bioelectrical information available on the body surface.

In our approach body surface potential map (BSPM) records were taken on healthy male and female subjects (age 20-80 years) and on ventricular arrhythmia patients, some of them with implanted cardioverter defibrillators (ICD). Records were taken continuously, for 5 minutes, in resting, supine position. Beat-to-beat QRS and QRST integral maps, Karhunen-Loeve (KL) coefficient time-series, RR and nondipolarity index (NDI) time-series were computed.

We have concluded that beat-to-beat dynamics of high resolution BSPMs are able to identify arrhythmia vulnerability, especially if the mean value of the KL components is low. The cycles yielding extreme NDI spikes have a heterogeneous repolarization distribution which is a necessary but not sufficient substrate for the initiation of malignant arrhythmias. The temporal distribution of NDI spike formations is random; the frequency is associated with the relative KL component noise levels. The increased spike formation is a sign of elevated arrhythmia vulnerability.

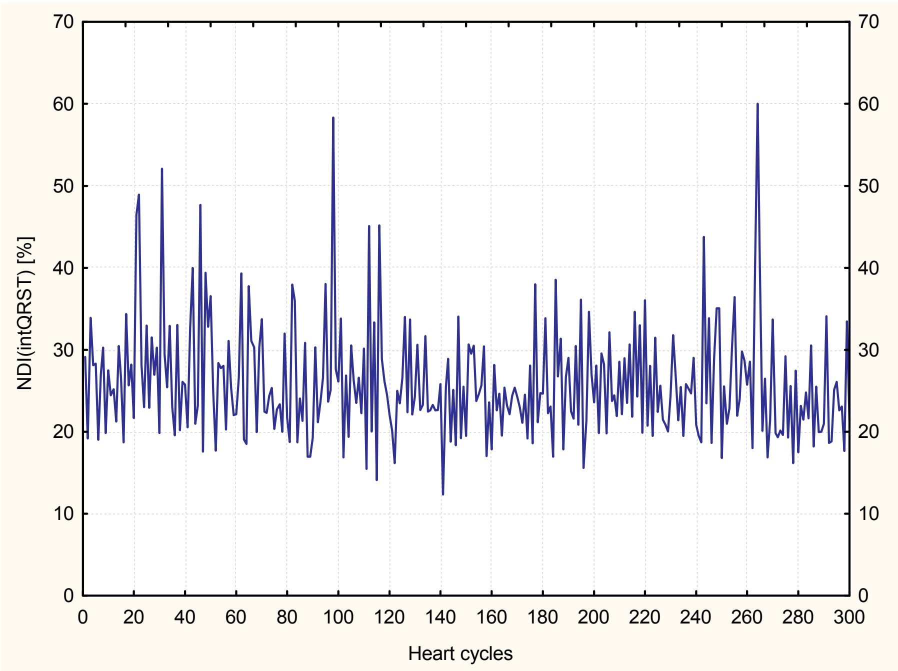

Fig. 5 *A typical 5 min train of subsequent heart cycles with frequent NDI spikes. The record was taken on a momentaneously asymptomatic ICD patient with verified episodes of malignant arrhythmias.*

Nanotechnology Department

Nanostructures Laboratory	Ceramics and Composites Laboratory	Complex Systems Group
Head: Zsolt E. HORVÁTH, Ph.D. **Staff:** József GYULAI, Prof. Emeritus, member of the HAS László P. BIRÓ, D.Sc. Attila Lajos TÓTH, Ph.D. Zofia VÉRTESY, Ph.D. Géza I. MÁRK, Ph.D. Antal A. KOÓS, Ph.D. Zoltán OSVÁTH, Ph.D. Margit SÁRKÁNY, technician **PhD Students (Advisor):** Enikő HORVÁTH (Attila Lajos TÓTH) Krisztián KERTÉSZ (László P. BIRÓ) Levente TAPASZTÓ (László P. BIRÓ & Géza I. MÁRK)	**Head:** Csaba BALÁZSI, Ph.D. **Staff:** Péter ARATÓ, D.Sc. László BARTHA, Prof. Emeritus, D.Sc. János CHALUPA, technician Ferenc WÉBER, M.SC. István GAÁL, C.Sc., part time Judit PFEIFER, C.Sc., part time **PhD Students (Advisor):** Balázs FÉNYI (Csaba BALÁZSI) Nikoletta KAULICS (Péter ARATÓ) Orsolya KOSZOR (Csaba BALÁZSI) **Undergraduate (Advisor):** Delgermurun DASHBALJIR (Csaba BALÁZSI)	**Head:** György SZABÓ, Ph.D. **Staff:** István BORSOS, M.SC. Zoltán JUHÁSZ, Ph.D. Géza ÓDOR, D.Sc. Attila SZOLNOKI, Ph.D. **PhD Student:** Jeromos VUKOV (György SZABÓ)

Nanostructures Laboratory

Production, modification and characterization of carbon nanotube-like nanostructures based on physical, chemical and simulation methods

(Hungarian Scientific Research Fund under Grant No. T 043685)

László P. BIRÓ, Zsolt E. HORVÁTH, Zofia VÉRTESY, Géza I. MÁRK, Antal A. KOÓS, Krisztián KERTÉSZ, Zoltán OSVÁTH, Levente TAPASZTÓ

Our theoretical model based on the interference of the scattered electrons (suitable to interpret the experimentally observed long-range interference patterns by considering coherent scattering processes allowed at finite bias voltages in carbon nanotubes), was generalized for arbitrary position of the Fermi level [164]. This way, the scattering processes on functional groups connected to structural defects of carbon nanotubes can also be interpreted.

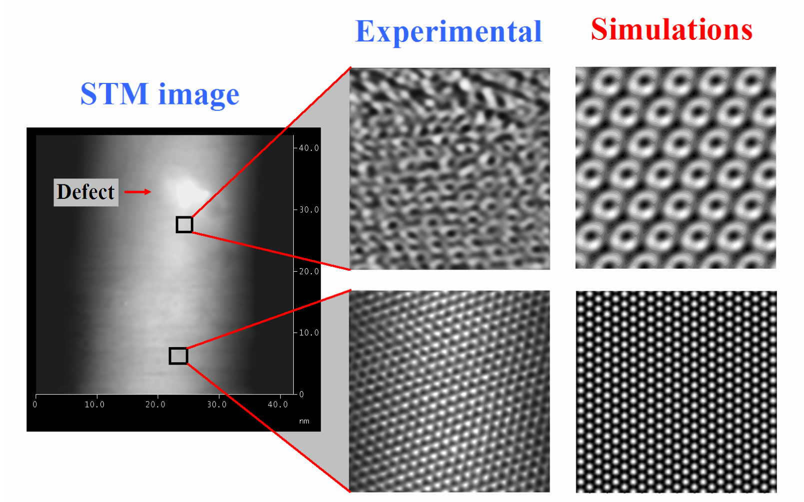

Fig. 1 *Experimental and simulated STM image of a carbon nanotube near a defect and in a defect free region.*

Comparing the STM image of a helical carbon nanotube and an Ar^+ ion irradiated carbon nanotube, similar hillock-like protrusions of several angstroms were found. They can be attributed to local structural defects of the hexagonal lattice of carbon atoms. In the case of the helical tube, these defects appear periodically, in approximately the same positions of the threads. This observation is in accordance with the common structural model of the helical nanotubes in which the regular curvature is generated by periodically incorporated nonhexagonal rings (pentagons and heptagons). To our knowledge, this is the first experimental result directly supporting the mentioned theoretical model (accepted for publication in physica status solidi (a)).

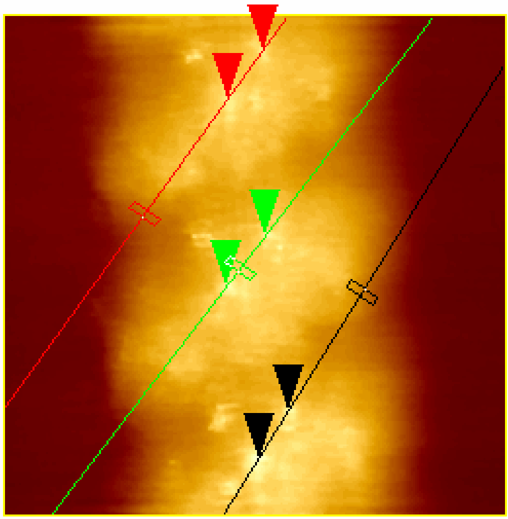

Fig. 2 *STM image of a helical carbon nanotube with periodically repeated hillock-like protrusions, denoted by coloured triangles. These protrusions can be attributed to structural defects of the hexagonal arrangement of carbon atoms.*

Nanotube-based gas sensor

(MEH-MTA strategic research grant NANOGAS)

József GYULAI, László P. BIRÓ, Zsolt E. HORVÁTH, Zofia VÉRTESY, Antal A. KOÓS, Krisztián KERTÉSZ

Gas sensing properties of different carbon nanotube (mostly multiwall, MWCNT) mats, based on electrical resistance measurement were investigated in a simple arrangement and found that the sensitivity for different gases or vapors highly depends on the pre-treatment and functionalization of nanotubes. Properly selected sets of such sensors perform well in identifying various chemicals after "fingerprinting" the gases/vapors to be identified. The selectivity of the sensing was demonstrated by building a vapor recognition system based on an array of multitube sensors made of differently functionalized MWCNTs [66, 81].

Photonic crystal type materials of natural origin

(Funded by INCO-12915/2005 EU6 NEST-Pathfinder „BIOPHOT" and Hungarian Scientific Research Fund under Grant No T 042972 "Comparative morphological and thermal study of butterfly wing scales…")

László P. BIRÓ, Zofia VÉRTESY, Krisztián KERTÉSZ, Géza I. MÁRK, Levente TAPASZTÓ

A new class of materials systems: the three dimensional (3D) nanoarchitectures pose new challenges to the analytical tools commonly used to reveal structures in the nm range. In these nanorachitectures not only the dimensions of the building elements, but their relative position with respect to each other in the full 3D space are equally relevant.

The dorsal scales of the butterfly Cyanophrys remus [77, MFA Yearbook 2005] have a complex 3D nanoarchitecture which is responsible on one hand for the bright metallic blue of the dorsal surface on the wings, when observed with the naked eye, on the other hand for the unusual way in which this structure reflects light [78]. The full 3D structure was reconstructed from SEM and XTEM images, the numerical simulations based on the model are in excellent agreement with experimental data [78].

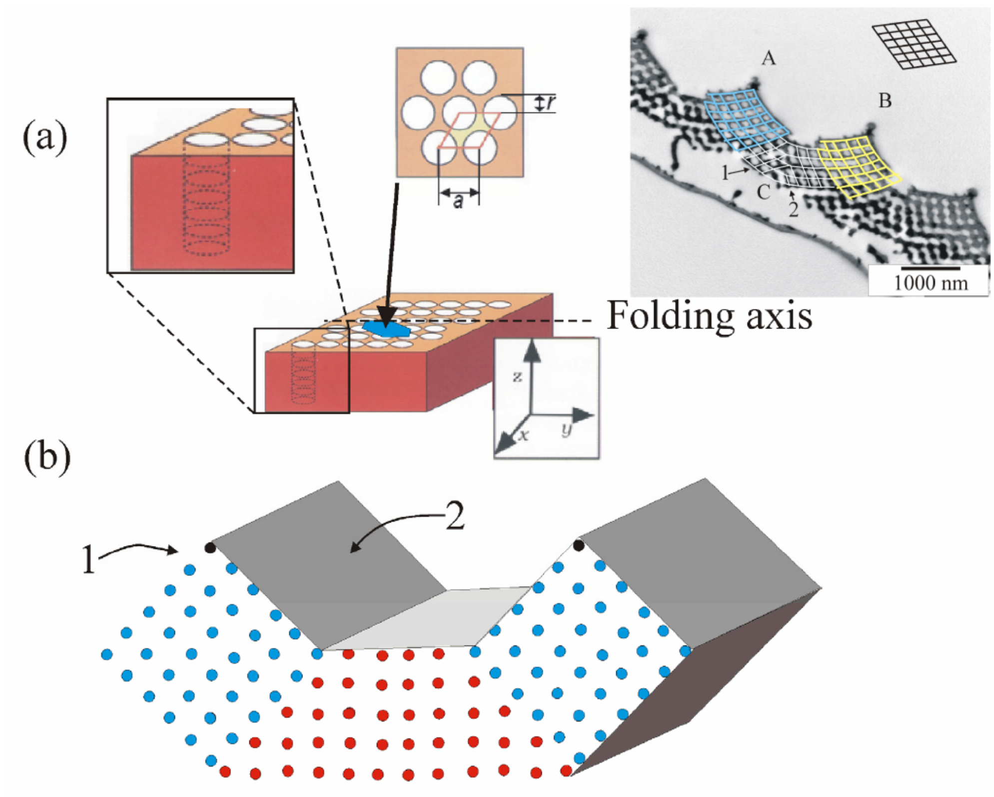

Fig. 3 *Model structure for the dorsal scales of the Cyanophrys remus. (a) a regular stack of layers with the triangular pattern of circular holes is built. For simplicity of the drawing, in this presentation the spherical hollows in the real scale have been replaced by their circular cross sections in the xy plane; (b) the two folded rods with square cross section — standing for the ridges — (folding axis labeled by heavy dots) are joined together by a third rod with trapezoidal cross section standing for the interridge region. For the sake of simplicity the spherical hollows are shown as their circular cross sections only in the plane closest to the observer, which corresponds to the xz plane of the stack shown in (a). Inset in the right upper corner shows an XTEM image of a butterfly scale.*

Nanofabrication by focused ion and electron beams

(Hungarian Scientific Research Fund under Grant No. T 049131)

Attila L. TÓTH, Zofia VÉRTESY, Enikő HORVÁTH, Zsolt E. HORVÁTH, Géza I. MÁRK, Antal A. KOÓS, Krisztián KERTÉSZ, László P. BIRÓ

Individual functionalized and non-functionalized multiwall carbon nanotubes were contacted to prepatterned microelectrodes with the help of electron- and ion-beam-assisted Pt deposition (EBAD and IBAD, respectively) in a dual beam SEM/FIB system. The used MWCNT families were previously characterized in a complex way and gas sensing properties of their random networks were also studied. All the contacted MWCNTs showed ohmic behaviour with resistance values between 0.5 and 1.3 Mohm at room temperature in ambient air. Electrical characterization of the samples at low temperatures and in different gas and vapor ambients are in progress.

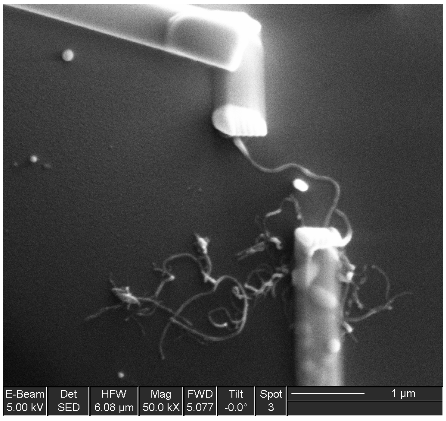

Fig. 4 *SEM image of a contacted individual multiwall carbon nanotube. A short part of the Pt electrodes directly connected to the tube were deposited by EBAD in order to avoid the degrading effect of the ion beam. The further, longer part of the Pt wires were deposited by IBAD.*

Ceramics and Composites Laboratory

Silicon Nitride-Based Ceramics and Composites

(Hungarian Scientific Research Fund under Grant No. K63609 and János Bolyai Postdoctoral Grant)

Péter ARATÓ, Csaba BALÁZSI, Orsolya KOSZOR, Judit PFEIFER, Ferenc WÉBER

Nanotechnology research aims to provide a fundamental understanding of phenomena and materials that enable the creation and use of devices and systems that have novel properties and function. The intensive study of ceramic composites started in this laboratory three years ago. The long-range aim is to develop new materials with a high level of synergism.

Composites with silicon nitride matrix and carbon nanotube (CNT) reinforcement have been in the focus of our interest. It is known that CNTs are characterised by exceptional mechanical and physical properties, however their incorporation into ceramic matrices gave only modest improvements. This discrepancy is caused by two facts, firstly, it is difficult to produce a homogenous distribution of CNTs in the ceramic matrix and secondly, their degradation at the temperature of sintering had to be prevented.

First our team succeeded to find processing parameters providing the maintenance of carbon nanotubes in a silicon nitride based matrix. In year 2006 we continued the investigation of CNT/silicon nitride composites. Samples were prepared with different compositions, sintering techniques (HIP, hot isostatic press, HP, hot pressing and SPS, spark plasma sintering) and processing parameters. Their micro and nanostructure were examined by scanning electron microscopy (SEM), X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR), mechanical and electrical properties were measured. We attempted to reach a better understanding the relationships between processing parameters, structure and properties.

Spark plasma sintering is one of the advanced sintering methods, its main benefit is the high heating and cooling rate (100 K/min and 400 K/min, respectively). Samples made from our materials were sintered in Arrhenius Laboratory. 3 - 5 min holding at 1500 ^{o}C was sufficient to reach 95-99% of density. Density, hardness and modulus of elasticity of samples with 1% CNT was only slightly less than that of reference sample, no difference between the values of toughness was observed. The grain size in both cases was about 200 nm, comparing to 400-500 nm of ceramics after usual sintering. SPS equipment is too expensive for mass production, it is able, however, to provide particular information on the nanostructure of ceramics and composites.

Image obtained by direct examination of structure can be supplemented by the information gained from results of measurements. The modulus of elasticity reflect well mechanism of deformation in the initial stage of sintering.

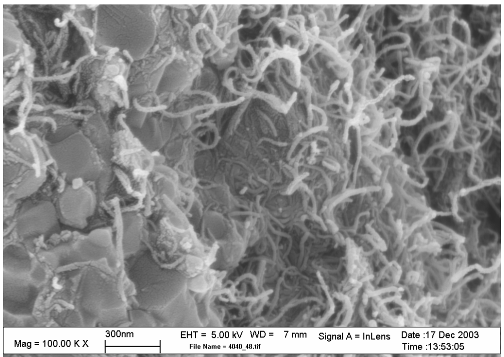

***Fig. 1** Microstructure of samples with 1% CNT sintered by SPS*

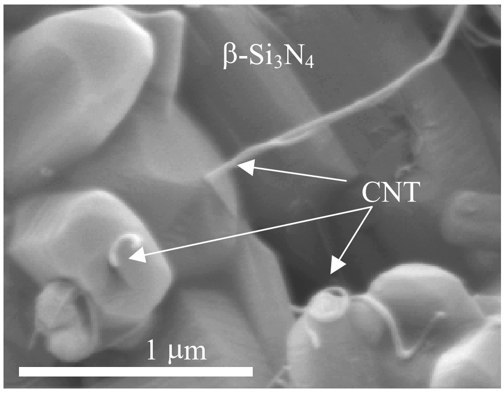

***Fig. 2** Microstructure of samples with 1% CNT sintered by HIP*

The dependence of mechanical properties on the quality and quantity of reinforcing phase and on the type of sintering process is shown in Fig. 3. The first logical step is the analysis of the modulus of elasticity, because this quantity does not sense such fine details of structure as the size and orientation of cracks or the probability of crack bridging. When the body contains only one ceramic phase and pore, the modulus of elasticity depends only on the density.

The density – modulus of elasticity curve for samples made with carbon nanotube additives is shown in Fig. 3. It is clear that the rate of densification decreased with increasing additive content as in the case of carbon black or graphite additions. At the same time the break in the density – modulus curve did not occur. This result suggested that the mechanism of densification did not change during sintering because the bond between ceramic phases and CNTs was strong.

Averaged four point strength values can be seen in Fig. 3 for samples realised by gas pressure sintering (GPS). Several temperature-time GPS runs were executed, the goal was to cover a wide porosity range. It is possible, considering the density-strength lines, to distinguish between two ranges of density. The value of density below 2.5 g cm^{-3} depended on the density but did not depend on the type of additive. At higher density the addition of CNT gave larger strength than the addition of graphite or carbon black.

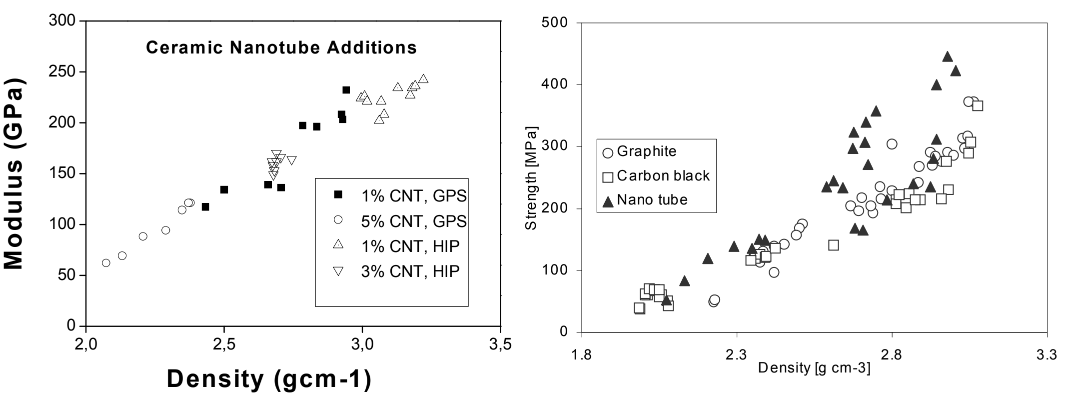

***Fig 3** The modulus of elasticity and four point strength as a function of density*

In addition to the mechanical properties physical characteristics were also measured. The DC specific conductivity was determined co-operating with the Miskolc University. It was found that 3 wt. % CNT is sufficient to alter the transport properties of the HIPed composites. The order of magnitude of electrical conductivity of silicon nitride ceramics is 10^{-11} - 10^{-12} S m^{-1} while its value in the composite was as high as 18 S m^{-1} [3-6, 8-11], at the same time the difference between mechanical properties of ceramic and composite was less than 50%. These data mean that the CNTs percolate providing the conductivity while the ceramics are bonded each to the neighbouring particles providing the mechanical strength. It is sure that a composite which is wear resistant, refractory and conductive will be used in a wide region.

Tungsten Oxide Functional Ceramics

(MTA-OTKA-NSF, MTA 91, Hungarian Scientific Research Fund under Grant No. 049953)

Csaba BALÁZSI, Judit PFEIFER

Tungsten oxide compounds, promising at sensing dangerous gases in the ambient have been prepared in order to use them as thin layers of functional ceramics. The synthesis was based on soft chemical methods: acidic precipitation and hydrothermal dehydration of potassium and sodium tungstate derivatives. The potassium tungstate precursor resulted in tungsten bronze structures with nanosize morphology. The same preparation method using sodium tungstate precursor resulted in metastable open structure derivatives, $WO_3.1/3H_2O$ and h-WO_3 with nanosize morphology as well. Powders of h-WO_3, c-WO_3 and m-WO_3 were used to deposit sensing layers at the Department of Materials Science & Engineering SUNY, Stony Brook. Responses of the sensors to NH_3 and NO_2 gases are shown in Fig. 4. The plots in Fig. 5 show the response of the sensing layer prepared from h-WO_3 to ammonia at various levels of ammonia in one dose. The films showed a decrease in resistance on exposure to NH_3 as is characteristic of an n-type semiconductor. The layers were found to be sensitive in the concentration range of 50-500 ppm [7].

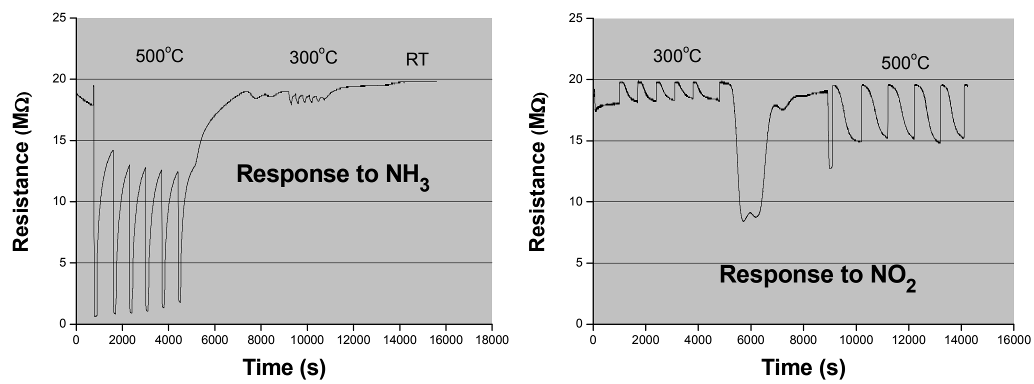

***Fig. 4** Sensitivity of cubic tungsten oxide sensor layer for ammonia and NO_2*

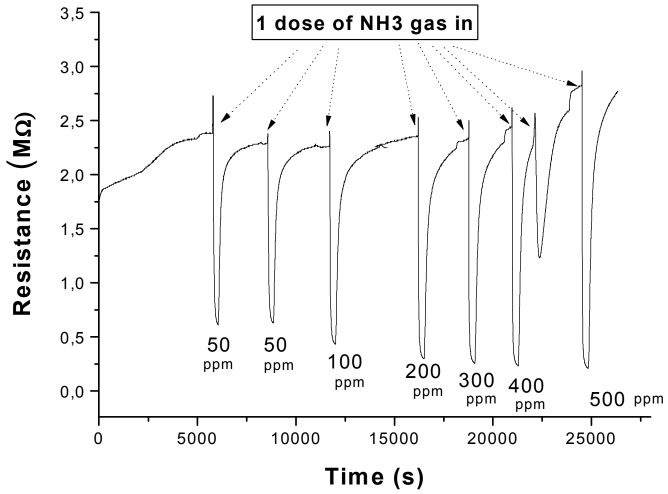

Fig. 5 *Sensing responses of h-WO_3 to various levels of NH_3 doses at 300°C*

Hydroxyapatite and Polimer Based Bio-Compatible Composites

(MTA-OTKA-NSF, MTA 91, Hungarian Scientific Research Fund under Grant No. 049953, and József Öveges program)

Csaba BALÁZSI, Ferenc WÉBER

The significant increase of the number of old people results in new aims for the materials of human implants. One of possible answers is to develop a material which does not damage the tissue at the surface of the implant and keeps an appropriate strength throughout decades of years. Another material imagined bears the mechanical load at the beginning, then promotes the formation of bone tissue and dissolves when its work becomes unnecessary. Experiments to work out processing technology for production materials with the mentioned characteristics are in progress in several research centres of the world.

Hydroxyapatite (HAP) is one of the ceramic materials often used in making implants. Its bio-compatibility is fine, its strength, however, is not high. We developed a processing technology starting from natural raw materials for preparing bio-compatible hydroxyapatite based composites. The procedure is advantageous from the point of view of protection of environments and energy saving, too. Steps of processing include techniques of soft chemistry and high temperature sintering, the size of particles is in the micrometer and nanometer ranges.

Our laboratory began to study various kind of ceramic- polymer composites this year in co-operation with State University of New York at Stony Brook. Electrospinning gave a three dimensional arrangement of polymer micro and nano fibres. This structure has high porosity and large specific surface, consequently provides good conditions for biodegradation.

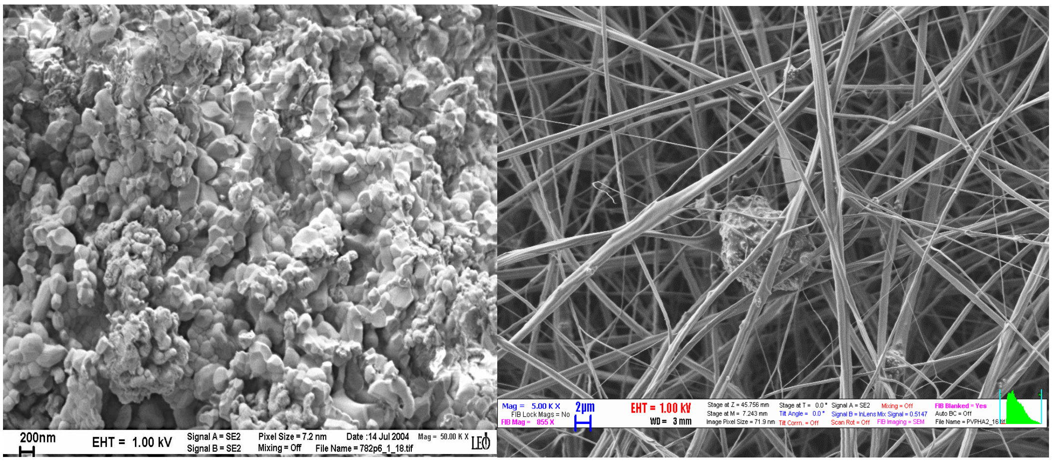

Fig. 6 *Nanocystalline hydroxiapatite from eggshell and fibrous structure of hydroxiapatite-polymer composite [26].*

In composites prepared in our laboratories hydroxiapatite nanoparticles were dispersed in a polymer matrix.

It is thought that the nanograins may be particular places for the regeneration of bone tissue. Our experiments on the interaction between composite and tissues are continued.

Materials for Light Sources with Improved Properties

László BARTHA, István GAÁL

Thoriated tungsten electrodes are often used in high intensity discharge lamps since thermionic emission of tungsten is markedly increased by the presence of Th atoms on the surface.

The evolution of the surface composition of thoriated tungsten has been followed up by means of Auger electron spectroscopy after various heat treatment performed below 2300 K. It turned out that the evolution depends dramatically on the current density of the electron beam exciting the Auger electrons, and no Th adatom enrichment has been observed without electron beam irradiation in this temperature region. It has been shown that the sources of Th adatoms are thoria particles attached to the free surface of the wire.

It is expected that the electron induced oxygen depletion of the thoria particles is the main reason for thorium release onto the free surface [44-46].

Complex Systems Group

Evolutionary Games

(Hungarian Scientific Research Fund under Grant No. T 047003)

György SZABÓ, Attila SZOLNOKI

Many phase diagrams are evaluated to classify the effects of noise, connectivity structure, and payoffs on the cooperation in the evolutionary Prisoner's Dilemma games. It is found that some types of inhomogeneities in the teaching activity can also promote the measure of cooperation.

The extended version of our previous model, describing the bacterial warfare with two toxins, has demonstrated the emergence of a self-organizing spatiotemporal pattern controlled by cyclical invasion among the favored associations of bacteria.

Most of our efforts were focused on writing a review paper on evolutionary games on graphs.

Nonequilibrium phase transitions

(Hungarian Scientific Research Fund under Grant No. T 046129)

Géza ÓDOR

The nonequilibrium systems can undergo phase transitions (e.g., extinctions) that can be classified by considering the universal features of the critical transitions. Our research is focused on some exceptions exhibiting unusual behaviors. The models are studied by Monte Carlo simulations and the extended versions of the mean-field methods.

Analysis of folk music

(Hungarian Scientific Research Fund under Grant No. T047003)

Zoltán JUHÁSZ

Each melody can be represented by a point in the multidimensional melody space. Adaptively weighted version of self-organizing mapping is developed to explore the basic roots of the Hungarian folk songs and also to find relations between the structure of the set of folk songs for different nations.

The number of songs and also the number of regions (nations), from which these song are originated, are increased continuously.

Activities

Scientific Promotions

Ákos NEMCSICS
University professor at the Budapest Politechnical Institution, Budapest, Hungary

Antal GASPARICS
Electromagnetic nondestructive material evaluation based on Fluxset sensor
Ph.D. – Budapest University of Technology and Economics, Budapest, Hungary

István Endre LUKÁCS
Makyoh topography for the study of mirror-like surfaces
Ph.D. – Budapest University of Technology and Economics, Budapest, Hungary

Géza I. MÁRK
Wave packet dynamical simulation of scanning tunneling microscopy of carbon nanosystems
Ph.D. – Facultés Universitaires Notre-Dame de la Paix, Namur, Belgium

Zoltán OSVÁTH
Investigation and modification of carbon nanotubes by ion beam and scanning probe methods
Ph.D. – Budapest University of Technology and Economics, Budapest, Hungary

Marianna SZERENCSI
A comparative electron microscopy and electron diffraction study of carbon structures
M. Sc. – Roland Eötvös University

Gergely PAVLISINEC
B.Sc. – Kandó Kálmán Faculty of Engineering, Budapest, Hungary

Conferences and Symposia Organized with MFA Contribution

Workshop on Nanomineralogy, January 19-20, 2006, Balatonfüred, Hungary

2006 International Conference on Tungsten, Refractory & Hardmetals, February 7-8, 2006, Orlando, USA

IAEA School on Ion Beam Analysis and Accelerator Applications, March 13-24, 2006, ICTP, Miramare, Trieste, Italy

FULLMAT project meeting, April 7-8, 2006, Budapest, Hungary

APCOM 2006, the 12th Int. Conf. Applied Physics of Condensed Matter, June 21-23, 2006, Malá Lucivná, Slovakia

NANOMAT 2006, Int. Workshop on Nanostructured Materials, June 21-23, 2006, Antalya, Turkey

48th IUVSTA Workshop – INNOVATIAL Training Course, on „Influence of Trace Elements on the Nucleation and Growth of Thin Films", August 26-31, 2006, Budapest, Hungary

20th EUROSENSORS Conference, September 17-20, 2006, Göteborg, Sweden

32nd International Conference on Micro and Nano Engineering, MME 2006, September 17-20, 2006, Barcelona, Spain

11th Joint Vacuum Conference, September 24-28, 2006, Prague, Czech Republic

THERMINIC 2006 - 12th International Workshop on Thermal Investigations of ICs and Systems, September 27-29, 2006, Nice, Côte d'Azur, France

Pannon Scientific Day, October 12, 2006, Nagykanizsa, Hungary

ASDAM`06, the 6th Int. Conf. Advanced Semiconductor Devices and Microsystems, October 16-18, 2006, Smolenice, Slovakia

5th IEEE Conference on Sensors, October 22-25, 2006, Daegu, Korea

Nanotechnology and Engineering Practice conference, November 14, 2006, Veszprém, Hungary

ICMNT2006, International Conference on Micro and Nanotechnologies, November 19-23, 2006, Tizi-Ouzou, Algeria

SSSI 2006, The 5th Int. Conf. Solid State Surfaces and Interfaces, November 19-24, 2006, Smolenice, Slovakia

Neumann Conference in remembrance of László Kalmár anniversary, December 14, 2006, Budapest, Hungary

MFA Seminar Talks

11 Jan 2006	Fanni MISJÁK: *Influence of dopants on the structure of Cu polycrystalline films*
18 Jan 2006	Géza ÓDOR: *Critical behavior of an even offspringed branching and annihilating random walk cellular automaton with spatial disorder*
1 Feb 2006	Péter HARMAT: *The ANTE Ltd. "…novelty is business with us…"*
8 Feb 2006	János LÁBÁR: *New trends in electron microscopy*
9 Feb 2006	Francois CALOZ (Diamond SA, Switzerland) and Loic CHEREL: (Data Pixel Sarl, France) *Passive Fiber Optical Component Industry: The Role of Test and Measurements*
15 Feb 2006	László MOLNÁR: (Energy Center p.c., EUN-EGB Energy Council) *Trends and strategies in energetics: Actual problems in Hungarian and European energy politics*
22 Feb 2006	András STER: *Big Bang's hot matter is a liquid*
1 March 2006	Tamás HORÁNYI: *Titanium dioxide in medical implanthology*
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